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AERODROME ILLUMINATION BY MEANS OF WATER-COOLED MERCURY LAMPS

by Th. J. J. A. MANDERS.

628.971.8 : 656.71 : 621.327.3

For the illumination of the landing area of an aerodrome a light source set up at the edge of the area is used which emits a flat, fan-shaped beam of light. Rough calculation shows that the beam must have a vertical spread of the order of 1° or less, while the luminous intensity must amount to more than 1 million candle power. For the realization of such a beam, water-cooled high-pressure mercury lamps are particularly suitable. A description is given of the mercury lamp SP 2 000 W, which for the purpose in view is provided with a cooling system with a closed water circulation.

For safety in making night landings on an aerodrome, in addition to an adequate beaconing of points around the aerodrome [1]), the first requirement is an efficient illumination of the landing area itself. From the nature of the case this area must, however, be quite free of obstacles such as masts and the like. The illumination, which naturally involves the setting up of apparatus at a certain height above the ground, can therefore only be installed along the edge of the landing field. The requirements which result from this condition for the construction of the light sources to be used will be briefly discussed in this article. It will be found that the high-pressure mercury lamp, particularly that with water cooling, is especially suitable for this purpose. Such a lamp provided with a closed cooling system will be described in detail.

Requirements for the illumination of the landing field

It is in general desirable that such a length of the landing area should be illuminated that the aeroplane upon landing and running out comes to a stop upon the lighted part of the field, and that such a width of the field should be illuminated that the pilot has plenty of leeway in choosing the spot where he shall land, and that there shall be no disturbing contrast to the right or left of his field of vision. According to the internationally established rules (C.I.E. 1935 and 1939) on the basis of these considerations minimum dimensions of 600 × 300 m are recommended for the part to be illuminated.

Since the pilot must not be blinded by the source of light, the illumination is arranged to be from only one side of the field, namely in such a way that the direction of the light rays is almost coincident with the direction in which the aeroplane moves in landing. Furthermore, in order not to form an obstacle and also for practical reasons, the light source may not be too high. An arrangement is thus arrived at like that sketched in *fig. 1*. The light source here throws a flat, fan-shaped beam on the field [2]).

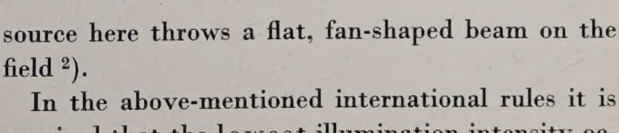

Fig. 1. Diagram of the arrangement of a landing light. φ vertical angle of spread of the beam. The height h is here very much exaggerated for the sake of clearness. Drawn to scale, h would be about $^1/_4$ mm in this figure.

In the above-mentioned international rules it is required that the lowest illumination intensity occurring, *i.e.* that at the farthest extremity of the part to be illuminated, must amount to 1.5 lux

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[1]) See G. L. van Heel, The illumination and beaconing of aerodromes, Philips techn. Rev. 4, 93, 1939.

[2]) The oblique illumination of the field causes long shadows to be cast by irregularities of the surface. In order to limit this undesired effect the light source will be set up in every case as high as is compatible with the objections mentioned.

(measured in a vertical [3]) plane). It is still better to count on a minimum of 2.5 lux. On the other hand it is recommended that the highest illumination intensity occurring, which is found at the side of the field near the light source, should be limited to 25 lux, in order not to spoil the adaptation of the pilot's eyes. In order to satisfy this requirement the light source is mounted at a sufficient distance (x in fig. 1) from the edge of the area to be illuminated.

If for the sake of simplicity we assume that the light beam is sharply bounded above and below and that the luminous intensity is constant over the whole vertical spread, we can easily calculate the required light intensity I and the angles of spread of the beam. When l is the length of the area to be illuminated ($l = 600$ m) the distance x follows from the condition that

$$\frac{I}{x^2} : \frac{I}{(l + x)^2} = 25 : 2{,}5,$$

$$x = 0{,}46\ l \approx 280 \text{ m}.$$

The light intensity thus becomes

$$I = 25 \cdot 280^2 \approx 2 \text{ million candle power.}$$

Between the height h of the light source above the ground and the vertical angle of spread φ the following relation is found:

$$\varphi \approx \frac{h}{x} - \frac{h}{l + x} \approx 0{,}0025\ h.$$

At a height of $h = 3.5$ m, $\varphi \approx {}^1/_2{}^0$. If the usual condition is made that the pilot must also be able to land at angles of up to 45° to the right or left of the direction of the beam, it follows (see *fig. 2*) that the horizontal spread of the beam must be at least 80°.

Actually of course it is impossible to create a beam of light with the sharp boundaries here assumed. The light intensity will decrease more or less gradually toward the edges. We have also entirely neglected atmospheric absorption in the above considerations. Nevertheless, it is sufficiently clear what unusual requirements are here made of the light source.

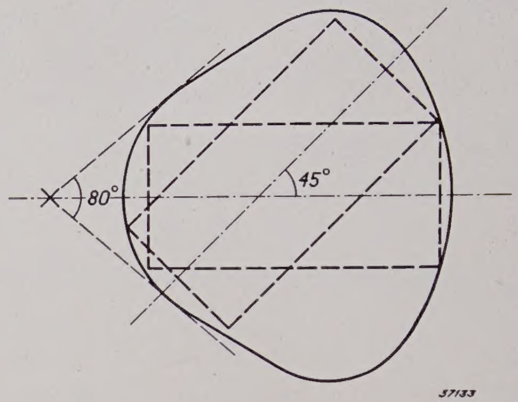

Fig. 2. Ground plan of the landing area upon which the illuminated part is indicated. Approaching in any arbitrary direction within an angle of 90° the pilot must have an illuminated area 300 × 600 m.

The most suitable method of obtaining the fan-shaped beam described is to place a lamp along the horizontally placed axis of a cylindrical parabolic mirror, see *fig. 3*. In the direction of the axis the luminous body may be fairly long. In order to keep the vertical spread of the beam small, however, the transverse dimensions of the radiating body must be small with respect to the dimensions of the mirror. If huge mirror constructions are not desired the lamps must be constructed with a very narrow luminous surface, while in order to obtain the necessary light intensity, the brightness of the radiating surface must be very high. It is possible to satisfy these requirements with suitably constructed electric filament lamps; *fig. 4* shows the filament systems which must be used. A more elegant solution of the problem, however, lies in the use of high-pressure mercury lamps which naturally have a linear form and a great brightness. The spectral composition of mercury light is also especially suitable for illuminating a green grass field with which most aerodromes are covered [4]) (either completely or surrounding the starting runways).

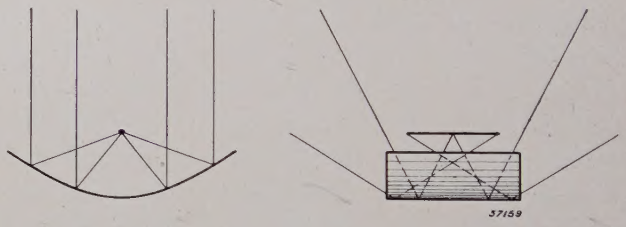

Fig. 3. Cylindrical parabolic mirror at whose axis the light-emitting body is situated.

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[3]) In connection with the oblique illumination the measurement on a vertical plane is called for. These measurements, however, usually also provide a good measure for the effect obtained (the brightness observed by the pilot), since the landing areas are usually covered with grass, so that the illuminated "plane" actually consists of numberless, almost vertical reflecting planes. The greatest brightness is actually observed in the direction of the illumination. The level of brightness then corresponds approximately to that on well-lighted roads with an illumination intensity of 3 to 10 lux.

[4]) See in this connection the article referred to in footnote [1]).

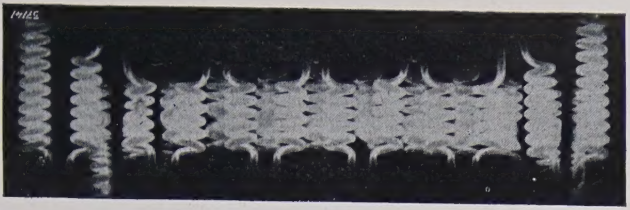

Fig. 4. In order to obtain the desired beam formation the light-emitting body must be made very narrow, while it may of course be long. The photograph shows the constructions used when the necessary light flux is to be obtained by means of a filament.

Air-cooled and water-cooled mercury lamps

In the article referred to [1]) a description has already been given of a high-pressure mercury lamp (HP 1000 W), which was developed for use in aerodrome illumination. With the help of a cylindrical parabolic reflector a maximum light intensity of 25 000 candle power was obtained, with an angle of spread of the beam of about 2° (by the angle of spread of the beam is meant the angle at which the light intensity has fallen to one half the value occurring in the direction of the axis). In order to obtain the desired illumination of the landing area, therefore, several of these lamps must be used.

Table I

Data of the water-cooled mercury lamp SP 2 000 W

Power consumed	2 000 W
Light flux	ab. 120 000 lm
Efficiency	ab. 60 lm/W
Length of discharge	50 mm
Greatest brightness (at axis)	ab. 30 000 cp/cm^2
Average life	150 hrs
Beam obtained (with reflector):	
vertical spread	ab. 1,1°
maximum light intensity	ab. 1,3·10^6 cp.

High-pressure mercury lamps have a greater brillance, the higher the power consumed per cm length of the discharge column [5]). Not only does the light flux increase with this power, but in addition the efficiency also rises, while the diameter of the light-emitting discharge decreases. Since the power which the high-pressure mercury lamp can consume is mainly limited by the heating of the tube wall, considerable improvement in brightness is obtained by applying a forced cooling of the tube wall. While in the case of the lamps type HP 1000 W mentioned, where the cooling had to take place by means of the surrounding air, a maximum brightness (at the axis of the discharge) of 1400 c.p./cm^2 occurs, when water cooling is employed values 20 to 30 times higher are easily obtained, and in laboratory tests values even 100 times as high [6]). In *table I* the various data are given for the water-cooled mercurylamp SP 2000 W, which, like the HP 1000 W, is especially intended for aerodrome illumination. It may be seen that even with one or two lamps the whole landing area can be illuminated. In *fig.* 5 the vertical and horizontal light distribution curves of the lamp with reflector are reproduced, while *fig.* 6 shows the distribution of the illumination intensity over the illuminated area.

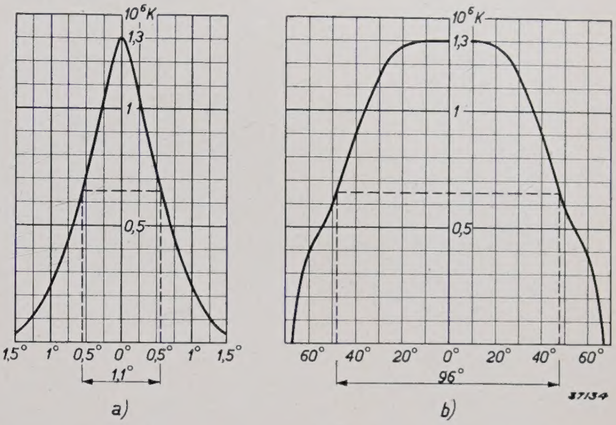

Fig. 5. Light distribution curve of the lamp SP 2 000 W in a cylindrical parabolic mirror; *a*) in a vertical plane perpendicular to the focal, line, *b*) in the horizontal plane through the focal line. The light intensity at the axis of the beam is 1.3 million candle power, the angle of spread in the vertical plane is about 1°, and in the horizontal plane about 90°.

Besides the economic advantages which result from the greater brightness (possibility of a better beam formation) and the higher efficiency, the water-cooled lamp has another important technical advantage over the lamp which is not artificially cooled. When a mercury lamp is switched on it must first become warm before it produces the full light flux. When the lamp is switched off, re-ignition is only possible after sufficient cooling of the lamp (decrease of the mercury pressure). While the lamp with natural cooling requires several minutes both for warming up as well as for cooling, the water-cooled lamp after being switched off is almost immediately ready for action again, and upon switching on, thanks to the high power consumed, it heats up to final temperature within a few seconds. These advantages are very important for an intermittent use such as will often be necessary on aerodromes.

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[5]) See for example Philips techn. Rev. **2**, 165, 1937 and the articles there referred to.

[6]) In this way it has been possible to exceed the brightness of the sun which is about 165 000 c.p./cm^2 (Philips techn. Rev. **1**, 62, 1936). In the article referred to in footnote [1]) the lamp described in the following, SP 2 000 W, which was then still at an experimental stage, was announced.

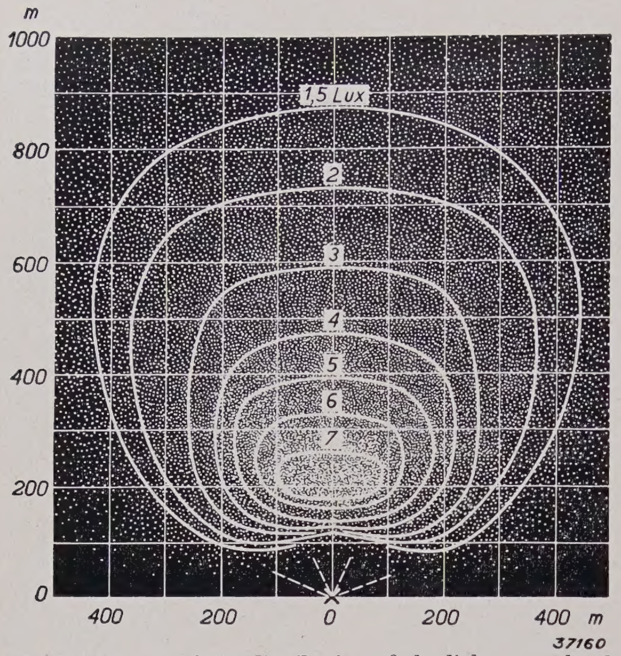

Fig. 6. Diagram of the distribution of the light over the illuminated landing area.

Construction of the water-cooling system

The way in which the water-cooling system is constructed is shown in *fig. 7* [7]). The quartz tube filled with mercury vapour is situated along the common axis of two cylindrical glass jackets. The water first flows through the inner cylinder and then flows back through the ring-shaped space between the two glass cylinders. The inlet and outlet for the cooling water are therefore both at the same end of the lamp, and the connection is made by means of the connecting piece shown is fig. 7. This forms at the same time the current lead to one electrode, while the current lead of the other electrode is insulated from the cooling water by means of a rubber cap over the end of the quartz tube (see figure). The connections for the current at one end and the inlet for the water at the other are so constructed and mounted in the reflector that when the lamp with jackets is adjusted, the light-emitting discharge automatically coincides with the focal line of the parabolic mirror.

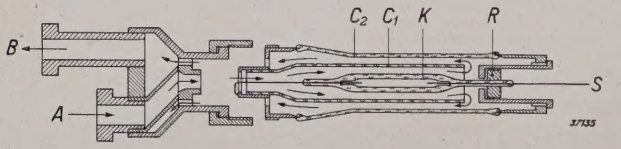

Fig. 7. Mercury lamp with water cooling. The water flows in at *A*, along the quartz tube *K* of the lamp inside the inner glass cylinder C_1, then between the cylinders C_1 and C_2 back again, and out at *B*. On the right the current lead *S* which is insulated from the cooling water by means of the rubber cap *R* which is pressed into place by a "Philite" cap.

An effective cooling is obtained by the double stream of water. While the light must indeed pass through a double layer of glass and water here, only a small amount of the visible light is absorbed, so that it constitutes no objection in this case. The necessary amount of cooling water with a permissible rise in temperature of the water of 70° amounts to 6 to 8 l/min. Due to the relatively small surface on which the transfer of heat can take place, fairly high speeds of flow must be maintained (about 5 m/sec), for which an excess pressure of 0.3 to 0.5 atmosphere is required.

From what source shall the necessary cooling water be taken? It would seem obvious that it should be taken from the local mains. For various reasons, however, this apparently simple solution is not satisfactory. In the first place, the position where the light source must stand for a landing is not usually fixed. The aeroplanes must in general land against the wind; therefore according to the direction of the wind the landing light must stand at different points along the edge of the landing area. Whether this condition is met by setting up a large number of lights around the aerodrome, from which a choice can be made, or by means of one movable unit, — in either case an elaborate network of water pipes would have to be laid for the cooling water. A second objection is encountered in the difficulty of protecting the pipe lines from freezing in the winter. And last but not least, the water from the mains is generally not pure enough, so that a deposit is quickly formed on the quartz tube of the mercury lamp. This deposit consists partly of the familiar boiler scale, often, however, of carbon and other substances which are formed by the decomposition of organic and other impurities present in minute quantities, probably due to the unusually intense ultra violet radiation to which the water flowing along the lamp is exposed. Such a deposit not only causes a lower light transmission and therefore a decrease in the yield of light, but it is also accompanied by a local overheating of the tube wall due to the greater absorption and the poorer transfer of heat to the water. This may result in the attack on the inside of the the tube (etching) by the mercury vapour, which then more quickly shows a tendency to break at the spots attacked.

Closed cooling system

All these objections can be avoided by providing the mercury lamp with a cooling system with a closed water circulation. The danger of freezing can then be avoided by adding a suitable anti-freeze substance to the water, while the water can be kept free of all impurities which might be subject to decomposition. As anti-freeze, alcohol with a trace of sodium phosphate is usually used. Because of the danger of decomposition it was found necessary to take care that the alcohol is also free of impurities. It was also found necessary to use a greaseless seal for the axle of the circulation pump, since the small amounts of grease which entered the water with the ordinary packing were also decomposed and again caused a deposit on the lamp.

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[7]) For special cases other constructions are also used besides the one described in the following. The inlet and outlet of the water may also be at opposite ends of the lamp.

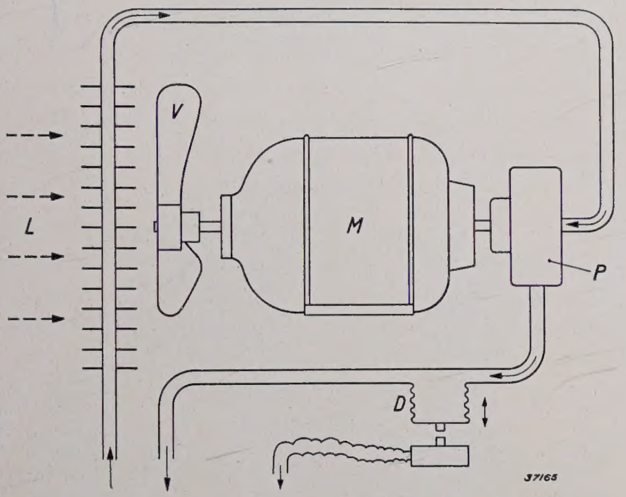

Fig. 8. Construction of the cooling system. The centrifugal pump *P* keeps the water in circulation. The electromotor *M* drives both the pump and the fan *V* which serves for the cooling of the radiator *L*. *D* is a pressure automaton which switches off the current when the water circulation is defective.

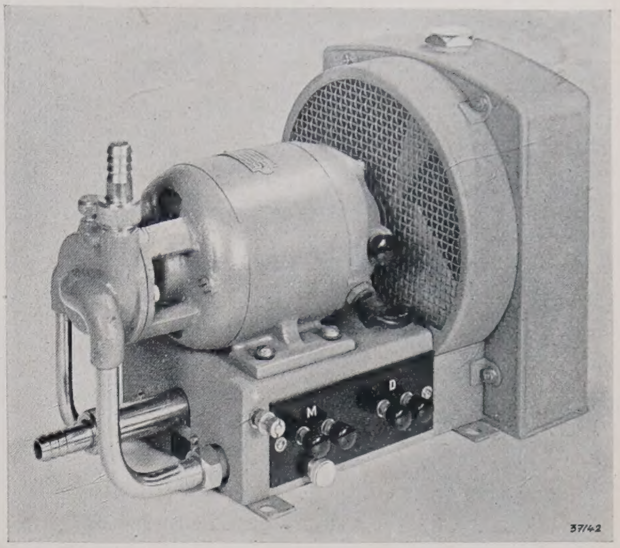

Fig. 9. Photograph of the cooling system.

The cooling-system constructed contains only about $1^1/_4$ litres of water. Considering the fact that for the mercury lamp SP 2 000 W, according to the above, 6 to 8 litres of cooling water per minute are necessary, after leaving the lamp the water has only about 10 sec to lose the heat it has taken up and to be cooled to the initial temperature. For this purpose a radiator of the type used in motor cars has been used. The radiator is cooled by means of a fan on the same axle as the centrifugal pump which makes the water circulate and driven by an electromotor of 150 W. *Fig. 8* and *9* show the arrangement.

If for some reason the circulation stops, then in order to prevent destruction of the mercury lamp the current must immediately be cut off. In the inlet connection of the cooling water to the lamp a pressure automaton is introduced for this purpose; its construction is indicated in fig. 8: the cooling water fills an accordion-like tube which expands more or less according to the water pressure and thereby depresses a push button which operates a switch in the current circuit of the lamp. If the pressure falls below a certain value, *i.e.* if the push button comes up far enough, the switch reverses and interrupts the current supply. By means of a setting screw on the push button, the pressure can be regulated at which the switching off will occur.

Fig. 10 shows how the cooling system and the reflector are combined to a unit. In this arrangement the air current sent through the radiator by the fan also contributes to the cooling of the reflector. The chassis is constructed as a section, *i.e.* if desired different complete systems can be set one above the other when one lamp is not sufficient. The reflector can be rotated about its focal line by means of a

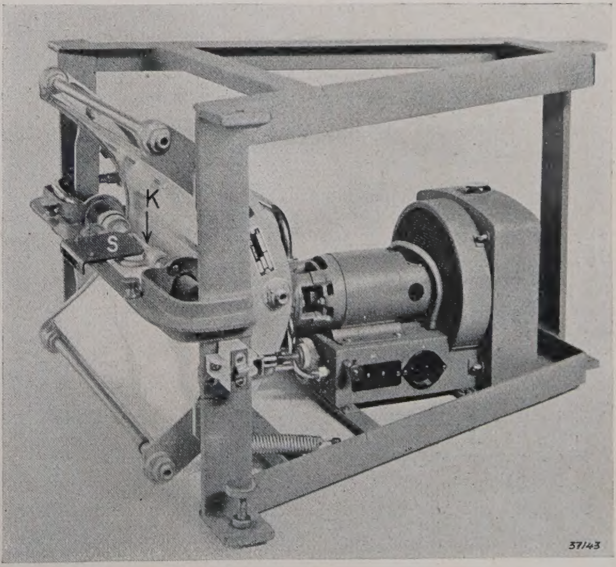

Fig. 10. Chassis with reflector and cooling system. The plate *S* screens off the light from the mercury lamp *K* which is directed upwards in order to prevent blinding. The fan contributes to the cooling of the reflector. Several units like the one shown can be piled one on top of the other.

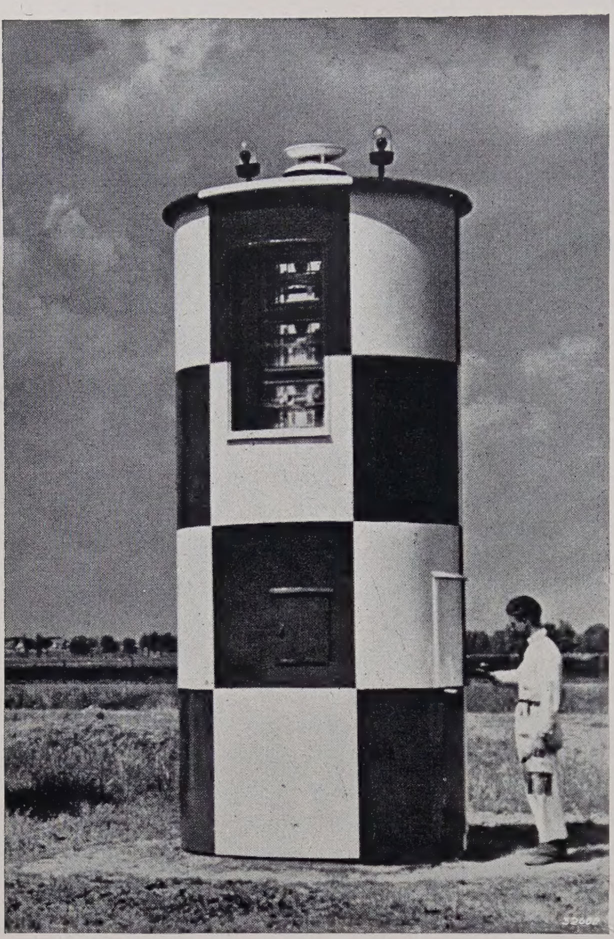

Fig. 11. Three units one above the other (fig. 10) are here mounted in a rain and sand-proof house.

screw, so that the beam can easily be set at the right angle, or when several lamps are used simultaneously the beams can be made parallel. The systems piled one on top of the other are mounted in a rain and sandproof house with a glass window, see *fig. 11*, so that the mirrors are protected against atmospheric influences. The necessary air for the cooling of the radiator is let in and out through a number of slits behind which a kind of labyrinth is placed to prevent the passage of rain, dust, etc.

For aerodromes in the country which cannot be connected to electric mains, or for cases where no lines can be laid around the whole aerodrome in order to obtain the necessary freedom in setting up the landing light, the latter is combined with a motor aggregate on wheels for generating the current. Such a unit is shown in *fig. 12*.

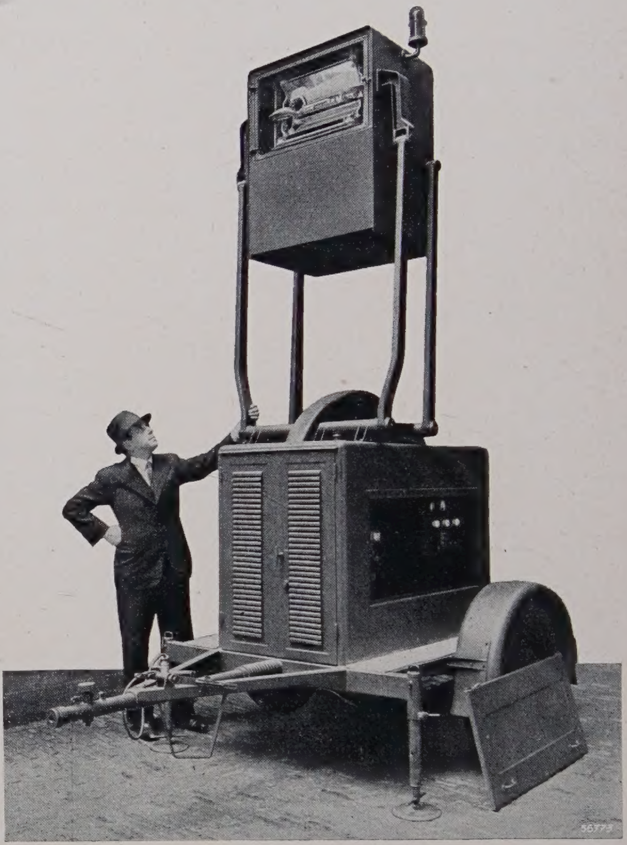

Fig. 12. Combination of a landing light with a petrol engine plus dynamo for the generation of the current. By means of a built-in winch and the lever parallelogram visible on the aggregate the light can be brought to any height between 2 and 4 metres. By adjusting the length of the feet of the car the fan-shaped beam can be made parallel to the surface of the landing area, and then by rotating the reflector about its focal line the beam may be directed on the field at the desired angle.

A RECTIFIER FOR SMALL TELEPHONE EXCHANGES

by H. A. W. KLINKHAMER.

621.314.634 : 621.316.722

For the supply of telephone exchanges which function entirely without supervision a connection in parallel of a rectifier and a battery is ordinarily used. The current-voltage characteristic of the rectifier must in this case, as explained in this article, satisfy very special requirements in order to ensure the desired constancy of the supply voltage, and at the same time to keep the battery in good condition. A description is given of a rectifier developed by Philips, whose characteristic possesses the desired general form. The calculation of the characterisitic shows that it consists of two separate branches, one for normal and one for heavy loading. As appears from a closer examination, this results in a particularly satisfactory behaviour of the rectifier when in use. Moreover, the output voltage of the rectifier is practically independent of mains voltage variations.

For the supply of telephone exchanges a D.C. voltage is in general required which must be able to be kept constant within very narrow limits. At too low a voltage the selecting elements, which make the connections, work too slowly, so that a wrong number may be obtained. At too high a voltage, spark formation, which is very detrimental to the life of the installation, increases very much, and this is intensified still more by the more rapid working of the selectors. In the case of the installations of the Netherlands Post, Telephone and Telegraph the condition is made that the supply voltage of the large exchanges must remain between 60 and 62 volts, independent of variations in the load.

Usually a combination of an accumulator battery and a converter or rectifier is used for the supply. The converter or rectifier, whose output voltage must remain within the limits given, even upon temporary voltage variations of the A.C. mains, serves for ordinary purposes, while the battery which is less economical in use, serves as a reserve when the mains voltage is interrupted by a defect (emergency use). Moreover, the battery serves to combat "cross talk". The microphones of all telephone subscribers are connected in parallel with the voltage source and are therefore coupled *via* the internal resistance of the latter. Current variations in one microphone therefore cause similar variations in all the other microphones unless the coupling resistance is made extremely small. This is accomplished by the permanent connection of the battery with its very low internal resistance, see *fig. 1*. When the battery has had to deliver current once, it must be recharged as quickly as possible in order always to have as large a reserve as possible. Furthermore, in order to keep it in good condition, the battery must be charged several times a month to a slightly higher voltage than the nominal (for example to 66 volts instead of 62 volts).

In the large exchanges the checking of the voltage and the maintenance of the battery can be entrusted to the operating personnel. In the case of small exchanges with only several hundred subscribers, however, one has to do without such personnel; maintaining the constancy of the voltage, in this case within somewhat wider limits, namely 57 to 63 volts, and the care of the battery must here therefore take place automatically. We shall in the following describe a rectifier with selenium valves (type No. 3028) which has been developed by Philips for these unattended exchanges, and which is adapted to a high degree to the special requirements of this purpose.

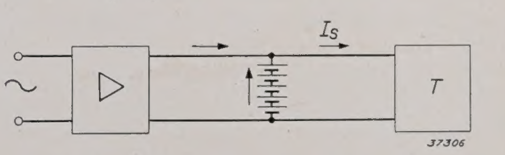

Fig. 1. Connection in parallel of rectifier and battery. The loading current I_s is distributed over selecting elements, microphones, etc. in the telephone network in connection, and the exchange *T*.

The general nature of the characteristic of the rectifier

It is easily understandable that an ordinary rectifier, *i.e.* a collection of valves, connected to the mains *via* an ordinary transformer, would be useless for the purpose in view. In the first place the D.C. voltage of 60 volts obtained, for instance, might already vary about 12 volts, due to the fact that the mains voltage may rise or fall as much as ten per cent above or below the nominal value. In addition there is still the voltage variation due to changes in the loading. The current-voltage characteristic of an ordinary 60 volt rectifier with blocking-layer valves exhibits a fall in voltage due to the voltage loss in the valves, which with full load may amount to 15 to 20 volts. If these variations are compared with the above-mentioned margin of 6 volts, namely from 63 to 57 volts, it is clear that different methods must be applied in the construction.

The permissible voltage limits for ordinary use actually become still narrower due to the following. The battery voltage is equal to the rectifier voltage, and with voltage variations which are not too rapid, the state of charge of the battery follows this voltage. It may now occur that the mains voltage falls back just at the moment when the battery voltage had adjusted itself at the lowest value for ordinary use. If one is to be sure that the battery in an emergency can then maintain the voltage above 57 volts for a given number of hours, the lowest voltage value for normal use may not lie below, say 60 volts, see *fig. 2*. The voltage margin for the rectifier, *i.e.* the permissible fall in voltage in the ordinarily employed section of its characteristic (*BC* in *fig. 3*) is thereby limited to a maximum of 3 volts.

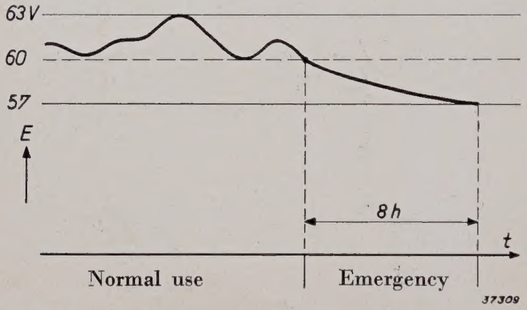

Fig. 2. In normal use the supply voltage may vary between the limits indicated of 63 and 60 volts, for instance. In emergency use, when only the battery functions, it may fall to 57 volts in 8 hours.

In addition to this statement about the part of the characteristic in normal use, it is also possible to say something about the ends of the characteristic, *i.e.* about the behaviour with small and large currents. With large currents a rapid fall is desired in order to prevent overloading of the blocking-layer valves. At very small currents a steep rise of the characteristic is useful (fig. 3). This means that upon very slight consumption the battery will be loaded not only to the normal maximum voltage of 63 volts, but to a still higher voltage, for instance to 66 volts. Since periods of very low consumption regularly occur at week-ends, the above-mentioned requirement of the periodic higher charging of the battery is automatically met. In this way one indeed comes into conflict with the requirement that the telephone automaton connected to the battery may not work at a voltage above 63 volts. Practically, however, no disadvantage is felt when the characteristic in this region is steep enough. A few calls are then already sufficient to cause the voltage to fall to 63 volts again. Upon each call a call converter is switched in which provides the call signal, and which continues to function during the entire conversation. This converter consumes a much higher current than is provided by the rectifier at the high voltage of 66 volts. Therefore under these conditions considerable charge is taken from the battery upon every call, while as may be seen from the discharge curve of the battery, only a very small part of its ampere-hours need be taken from the battery to cause its voltage of 66 volts to fall to 63 volts.

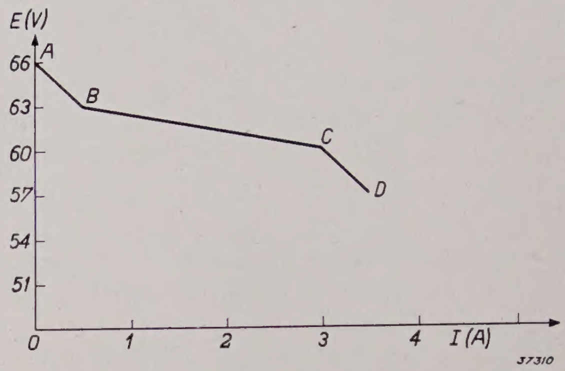

Fig. 3. Desired form of the rectifier characteristic. The section *BC* is used normally, *CD* during peak loads, *AB* in periods of very low loads (week-ends).

The characteristic actually obtained will in the following be compared with fig. 3, which represents roughly the desired form of rectifier characteristic.

Construction of the rectifier

The connections of the rectifier are given in *fig. 4a*. Their action can best be explained by first considering the simpler connections of fig. 4*b* which have long been used by Philips [1]). The iron core of the transformer T_1, which is connected to the mains *via* a condenser, is highly saturated at normal currents, the field of the iron and thus also the secondary voltage E_1 therefore remain practically

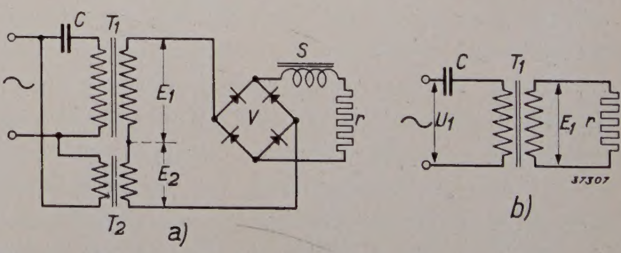

Fig. 4. *a*) Connections of the rectifier. T_2 is a normal transformer, T_1 a transformer with a highly saturated iron core. *V* are four selenium valves in the Grätz connection, *S* a smoothing choke, *r* a loading resistance.
b) Simplified connections. The output voltage E_1 is here insensitive to mains voltage variations, but not yet insensitive to load changes.

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[1]) See this periodical **2**, 276, 1937.

constant in spite of fairly large variations of the mains voltage U_1. However, upon variation of the secondary current, as a result, for instance, of a change in the loading resistance in direct connection or connected *via* rectifier valves, E_1 is found to change quite considerably in magnitude and especially in phase (with respect to the mains voltage).

The D.C. voltage obtained by rectification of E_1 is proportional to E_1 in the first instance, and the voltage losses must be subtracted which occur in the valves, in the winding of the transformer, etc. Since E_1 and these losses are all independent of mains voltage fluctuations, this is also true of the D.C. voltage obtained, so that the chief condition is satisfied. Due, however, to the variation of E_1 with the current taken off and to the fact that the voltage losses mentioned increase rapidly with the current, the relation between D.C. voltage and direct current produced is by no means found to possess the desired form. The slope of this characteristic in the ordinary loading region is much steeper than that corresponding to the section *BC* of fig. 3.

In the complete connections of fig. 4*a* the secondary voltage E_2 of a small transformer T_2 working at normal iron induction is in series with E_1. While the vector E_1 changes in phase and magnitude when the current taken off varies, the vector E_2 thereby remains constant in phase and magnitude. By giving the transformers suitable dimensions, provision may be made that the sum of the two vectors remains nearly constant in the normal region of currents, or even that it increases with increasing current. In this way the characteristic can be given the desired slope. This will become clearer from the calculations to be given presently [2]).

As concerns the behaviour of the rectifier at higher currents than normal, the calculations show that the characteristic here deviates considerably from the form given in fig. 3. The shape obtained however, is found to provide an even more satisfactory functioning of the rectifier than could be expected from the shape of fig. 3.

The calculations are given below.

Calculation of the characteristic

The calculation may be carried out with the help of the equivalent circuit diagram given in *fig. 5a*. The transformer T_1 is here represented by the admittance $-ju$, the valve square with the load connected is replaced by an ohmic resistance with the admittance g. The admittance of the condenser C is assumed to be jv. The transformer T_2 is replaced by the constant A.C. voltage U_2.

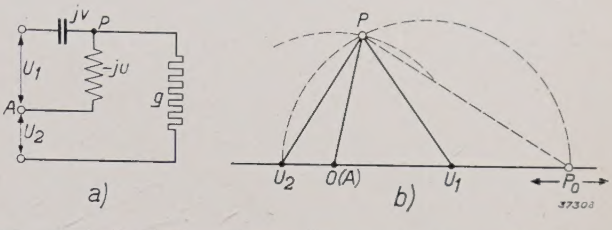

Fig. 5. *a*) Equivalent-circuit diagram for the rectifier connections of fig. 4*a*.
b) Vector diagrams of the equivalent circuit. At a given value of the admittance *u* (to be considered as a parameter) the point *P* can be found as the point of intersection of the two circles indicated by broken lines.

At a given value of the admittance g a certain A.C. voltage will act over it and a certain alternating current will flow through it. The relation occurring upon variation of g between these alternating voltages and currents, the "A.C. characteristic", which (except for the voltage losses) gives a picture of the required rectifier characteristic, is constructed by means of the vector diagram. This is of course not permissible, strictly speaking, since the elements of the network are not all independent of the voltage, and the currents and voltages are therefore not sinusoidal: the self-induction u varies when the A.C. voltage acting on it changes, according to the magnetization curve of the transformer core. Nevertheless it is found that no large error is made when the vector diagram valid for sinusoidal voltages is used [3]).

The vector diagram is given in fig. 5*b*. The potential of point A in fig. 5*a* is set equal to zero, the complex potential of point P is indicated by the same letter P. The potentials U_1 and U_2 are opposite because of the direction of winding of the transformer T_2. The voltage P-U_2 acts on g, the current through g is $g(P-U_2)$. The behaviour of these two quantities upon variation of g can be derived most simply by using u as a parameter. For every value of g a certain value of u will be effective, and for a given value of u the point P in the diagram may be found as the intersection of two circles: firstly the circle around the origin with the radius $|P|$, which according to the magnetization curve (measured with alternating current) corresponds to the given value of u; $P-0$ is the A.C. voltage on the self-induction. Secondly the semi-circle constructed through the points which represent the potential U_2 and a potential $P_0 = U_1 \cdot v(v-u)$. For the potential P from the condition that the sum of the currents at this node is equal to zero, the following equation is obtained:

$$g\,(P-U_2) = juP + jv(U_1-P),$$

or

$$g\,(P-U_2) = (u-v)\,j\left(P-U_1\,\frac{v}{v-u}\right) \quad . \; . \; . \; . \quad (1)$$

Since g and $(u-v)$ are real quantities, the voltage vector

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[2]) Since E_2 varies at the same time as the mains voltage varies, it might be thought that the action of the highly saturated transformer T_1 would to some degree be rendered fruitless. Actually, however, due to the addition of E_2 it is found that the dependence of the output voltage on mains voltage variations can even be still further decreased; see also fig. 10. All this holds only for the normal mains frequency. Upon variations in the frequency the output voltage also varies, relatively about 1.6 times as much as the freqency.

[3]) The errors can only be large at small output currents (<0.7 amp) where the voltage on u and thus the iron induction is the highest. In the following considerations however, it is primarily just with the region of higher currents with which we are concerned.

P-U_2 according to this equation is always perpendicular to the voltage vector P—$U_1 \cdot v(v-u)$, *i.e.* P lies on the semi-circle mentioned. When P has been constructed in this way for a value of u, a point on the required A.C. characteristic is also found, since the distance P—U_2 gives the voltage on g and the distance P—$U_1 \cdot v/(v-u)$ multiplied by $u-v$ according to equation (1) indicates the current through g.

If the construction is carried out for a large number of values of u, then, with the magnetization curve valid in our case, the point P describes the line given in *fig. 6*. From this, by measuring point by point the distances indicated, the A.C. characteristic is found, see *fig. 7*.

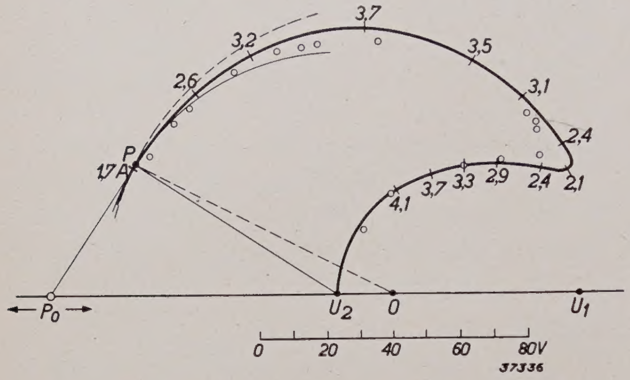

Fig. 6. Line described by the point P found according to fig. 5*b*, when different values are successively chosen for u. At each point P (and corresponding P_0) the length of the two lines P—P_0 and P—U_2 gives two corresponding values of output alternating current (numbers along the curve) and A.C. voltage and thus a point on the "A.C. characteristic". The small circles give several points determined by measurements which are found to coincide well with the calculated curve.

It is instructive to make a comparison between the complete connections of fig. 4*a* and the simplified connections of fig. 4*b*. The vector diagram for the latter would correspond in nature with that in fig. 5*b*, except that U_2 would have to be set equal to zero, and the second circle which furnishes point P would thereby change slightly for each value of u. The curve in fig. 6 (line described by point P) would in this case remain practically uncharged; as output voltage, however, the distance from P to 0 would have to be taken (broken line), which falls rapidly with increasing current, while on the contrary the distance from P to U_2 occurring as output voltage in the actual connections exhibits an increase with increasing current [4]).

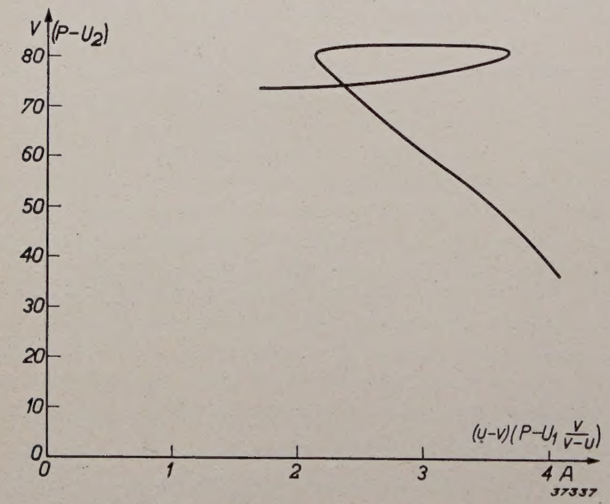

Fig. 7. A.C. characteristic drawn with the help of fig. 6.

After subtraction of the various voltage losses the D.C. characteristic of the rectifier is found from the curve of fig. 7. Considering the fairly rough approximation, this curve is found to agree quite satisfactorily with the measured characteristic which is reproduced in *fig. 8*.

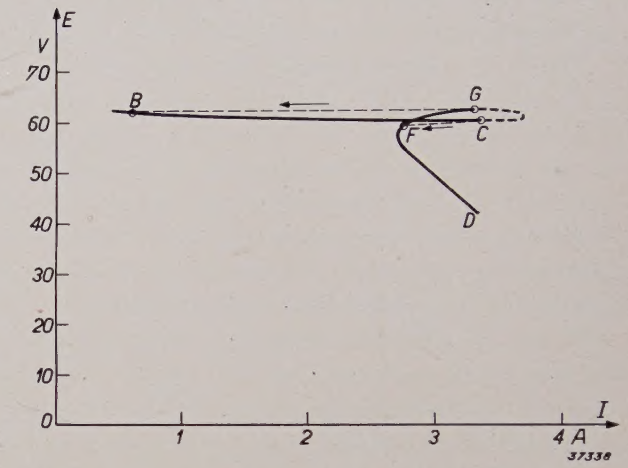

Fig. 8. Measured characteristic of the rectifier. The operating points on the loop which join the branches BC and DFG are not stable, so that a transition between the two branches can only take place by jumps, namely from V to F and from G to B.

Behaviour of the rectifier in action

In the characteristic obtained of fig. 8 it can in the first place be ascertained that the normally used part (corresponding to BC in fig. 3) meets the requirements very well: the output D.C. voltage at a loading with 3 amps. (the highest normally occurring) lies only about 3 volts lower than with $^1/_5$ of this load.

The end of the characteristic toward high currents has a very remarkable shape. A separate branch here occurs which shows a fall similar to that sketched in fig. 3 (CD). This branch is connected by a loop to the rest of the characteristic on which the operating point is situated upon normal loading [5]). Upon closer consideration, however, it is found that not all the operating points on this loop are stable. When the operating point, moving along the line BC, reaches C where the voltage is 60 volts, it then jumps from there to F on the other branch and runs along the line FD. Moving in the opposite direction, however, it passes from D through F to G, corresponding to a voltage of 63 volts, and then jumps suddenly to B on the first branch.

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[4]) The behaviour of the output voltage can be still better adapted to the requirements if the point U_2 is laid slightly below the extension of the line 0—U_1. In order to obtain such a phase difference between U_1 and U_2, however, a three-phase mains would be needed.

[5]) Qualitatively it is immediately clear that the connections behave quite differently in this region (low voltages on u): the iron of T_1 is here no longer saturated, the self induction therefore becomes so great, *i.e.* the admittance $-j\omega$ so small, that this branch of the equivalent circuit fig. 5*a* can be entirely neglected. We then have simply a condenser and a resistance connected in series with the voltage $U_1 - U_2$; in this region point P in the vector diagram therefore moves along a semi-circle constructed through U_1 and U_2.

This remarkable form of the characteristic is particularly favourable for the maintenance of the battery. Every time such a long continued high loading occurs that the battery voltage falls below the limit of 60 volts desired for ordinary use (*i.e.* every time the operating point tries to fall along BC over C), the rectifier begins to work on the branch DFG and continues to work on it even after the conclusion of the peak loading. This means that the battery, discharged to a low voltage, which has had to supplement the rectifier current up to the desired higher value during the peak loading, is again charged with the full rectifier current of 3 to 3.5 amps, until its voltage has risen to 63 volts (operating point G). Only then does the rectifier current suddenly fall to a lower value (0.7 amp. at point B). One may therefore be sure that after a peak loading the whole reserve of the fully charged battery will be available in the shortest possible time, and on an average the battery voltage will be much closer to the maximum of 63 volts than could be reached with a characteristic according to fig. 3.

The behaviour described is well illustrated by the record given in *fig. 9*, on which the current is recorded which was delivered by the Philips rectifier during several hours of normal use in a small so-called end exchange of the Netherlands Telephone. The strong fluctuations in which the current does not rise above about 2 amps, indicate that the rectifier continually adapts its current delivery to the load, and the operating point shifts back and forth on the section between B and C of the characteristic. At several load peaks, however, it may be seen that the current rises to 3 amps; at these points the battery voltage was 60 volts. The current is then maintained for a moment at the high value (the slight variation in these truncated high peaks indicated a shift of the operating point to the branch DFG) until the battery voltage has again reached 63 volts. At the end of each peak the current suddenly falls again to a low value.

Upon variations in the mains voltage the rectifier voltage remains practically unchanged, as was stated above. This is clearly shown in *fig. 10*, where the characteristic measured is given for three values of the mains voltage. It is remarkable that the output voltage of the rectifier for a low mains voltage lies even slightly higher than for a high mains voltage.

If after a long continued defect in the mains the battery is entirely discharged, and it is desired to charge it up as quickly as possible, the rectifier can furnish a higher current of for instance 4 amps by a commutation (T_2 in fig. 4*a* is short circuited, C is increased).

The "week-end voltage"

In the above calculation and discussion of the rectifier characteristic it did not appear whether or to what degree the apparatus described satisfies the requirement that at very small currents the voltage must rise approximately as in the section AB of the curve in fig. 3.

If we now consider more closely the connections consisting of a rectifier, a smoothing choke, a bat-

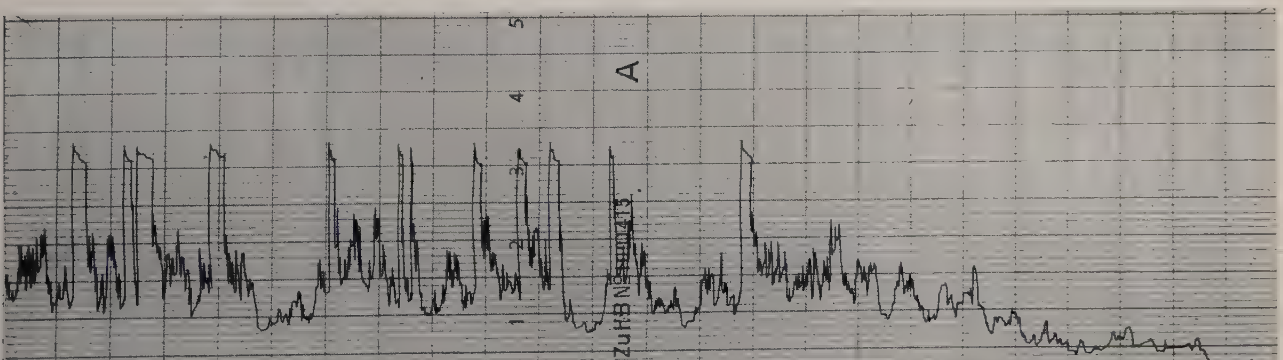

Fig. 9. Registrogram of the direct current delivered by the rectifier during several hours of normal use in a small so-called end exchange of the Netherlands Telephone. At the truncated peaks of about 3 amps. the rectifier was working on the steep branch of the characteristic (DFG in fig. 8). .

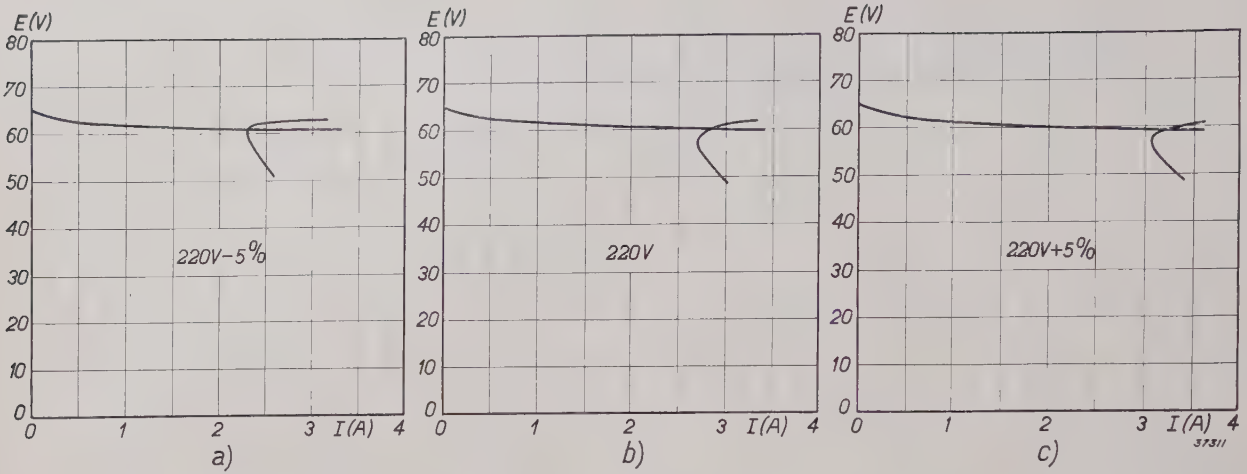

Fig. 10. Measured characteristic of the rectifier at a mains voltage lowered 5% (*a*), at normal voltage (*b*), and at a mains voltage raised 5% (*c*).

tery and a loading resistance (*fig. 11a*), it is found that such a rise in the characteristic as mentioned above occurs of itself. In order to understand this one must first consider the circuit with the battery missing. The rectifier gives a commutated A.C. voltage (fig. 11*b*), the choke, however, which acts as a kind of "flywheel", keeps the current through the resistance constant except for a slight ripple. Therefore an almost constant voltage acts on the resistance which is equal to the average value of the voltage of fig. 11*b*. If the battery is now connected in parallel with the resistance and if its voltage is exactly equal to the average value mentioned, the circumstances remain the same. It is true that in the shaded part of the curve the counter EMF of the battery is higher than the voltage given by the rectifier; one might therefore think that the valves would be loaded in the blocking direction and thus no longer transmit current. Actually, however, the choke delivers a voltage which supplements the momentary rectifier voltage to the amount of the counter EMF. In other words, the choke by its flywheel action prevents the current interruptions which might occur. The choke can do this when its self-induction and the average current are high enough. If the latter is now made smaller and smaller, the choke will finally no longer be able to deliver the required voltage during the whole shaded period, current interruptions occur. This means, however, that the rectifier begins to furnish a large proportion of the total current at moments when its momentary voltage is higher than the counter EMF of the battery, *i.e.* the battery is charged and the whole adjusts itself to a higher average D.C. voltage. In the extreme case when the load is zero. the process of charging the battery by the peaks of the voltage of fig. 11*b* will proceed until the battery voltage has become equal to the maximum value of the commutated A.C. voltage.

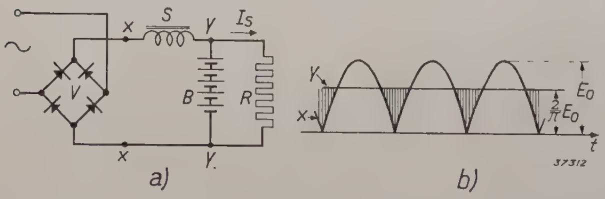

Fig. 11.*a*) Connections of rectifier valves V_1, choke *S*, battery *B* and loading resistance *R*.
b) Commutated A.C. voltage (peak value E_0), which acts on the terminals *x*-*x* in (*a*). A practically constant voltage with a magnitude of $(2/\pi)$. E_0 acts on the terminals *y*-*y*. If the loading current I_s is very small, the rectifier no longer delivers current throughout the whole period of the A.C. voltage, but chiefly at the moments when the commutated A.C. voltage exceeds the counter EMF of the battery.

This is actually what was desired, except for the fact that the rise of the characteristic generally begins at too large currents, since the self-induction of the choke cannot be made indefinitely large, and therefore already at relatively high currents it is no longer sufficient to suppress current interruptions entirely. In order to obtain the desired steepness of the characteristic in this region in spite of this, a second choke with a closed iron core is connected in series with the smoothing choke. At normal currents the iron is saturated, the self-induction is therefore small and the choke may be considered not to be present. At small currents, however, where one still works on the steeply rising branch of the magnetization curve of the iron, the self-induction is very high, so that here the choke still prevents current interruptions down to very small loads. This effect can be seen in *fig. 12*.

If the load remains zero or very small for very long (quiet period of the week-end) the operating point then slowly climbs up the steep left-hand extremity and the battery, as desired, is charged to a voltage higher than 63 volts. The heights of this maximum voltage will depend upon the circumstances, *i.e.* upon the number and distribution of the calls. In order to ensure that the batteries in all the exchanges are charged to the same excess voltage on Monday morning, a variable resistance (so-called basis load) is connected to the rectifier in parallel with the battery. By taking off in this way a larger or smaller no-load current from the rectifier, a larger or smaller piece of the characteristic is cut off on the left-hand side (fig. 12). Due to the fact that the characteristic rises so steeply here, the "week-end voltage", which without any loading would rise to 75 volts, can be reduced to the desired voltage of for instance 66 volts with a basis load of only a few watts. In the photograph of *fig. 13* the screw with which the basis load and thus the week-end voltage can be regulated may be seen at the upper centre. In this photograph the other components of the circuit may also be seen and are referred to in the text below the figure.

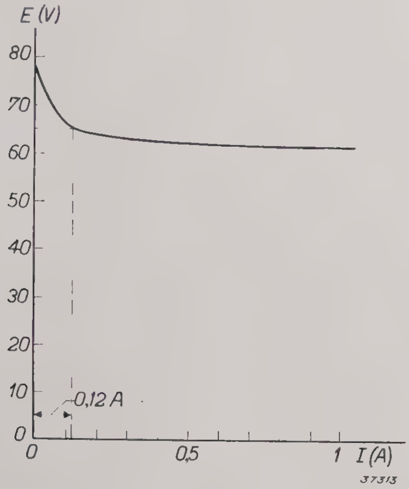

Fig. 12. Beginning of the characteristic of the rectifier with chokes. By means of a small basis load (about 0.12 amp.) such a piece is cut off the left-hand end of the characteristic that the desired maximum voltage ("week-end voltage") occurs.

Summarizing it may be said that the rectifier here described, because of its independence of mains voltage variations and because of the form of its characteristic, guarantees satisfactory functioning of the telephone automaton and maintenance of the battery. Thanks to the steepness of the characteristic at large currents, overloading of the blocking-layer valves is made impossible. This also makes possible the direct connection of the rectifier in parallel with a second rectifier, for example upon enlargement of the exchange. The fact that due to unavoidable small differences in the characteristics the load will generally be divided very unevenly over the two apparatus, constitutes no objection because of the impossibility of overloading. The efficiency of the apparatus in normal use amounts to about 65 per cent. The power factor is 0.57, with current leading, however, so that the apparatus helps to improve the power factor of the mains.

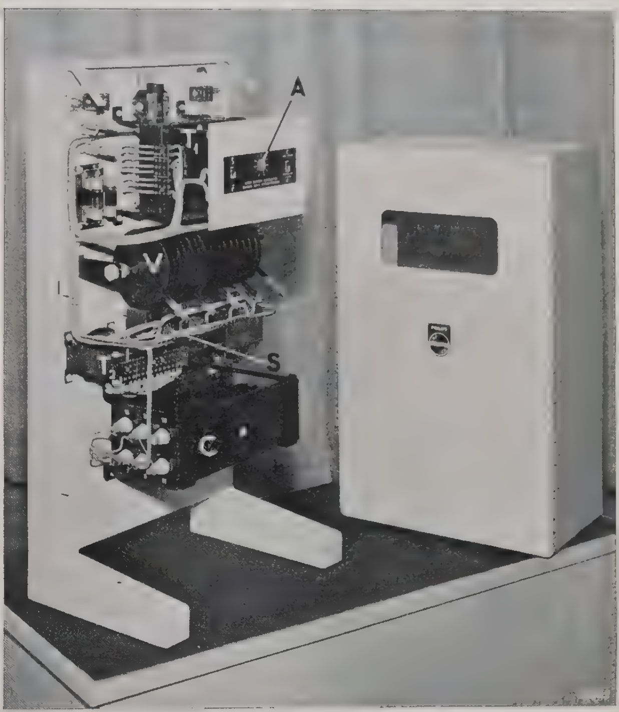

Fig. 13. Photograph of the apparatus opened. *C* condenser (see fig. 4*a*), T_1 highly saturated transformer, T_2 normal transformer, *V* selenium valves, *S* chokes, *A* screw for regulating the "week-end voltage".

AN APPARATUS FOR THE TRANSMUTATION OF ATOMIC NUCLEI

by F. A. HEIJN and A. BOUWERS.

539.172 : 621.319.52

For the transmutation of atomic nuclei use may be made of ions which have been accelerated by a high voltage and with which the atoms to be converted are bombarded. An apparatus for this purpose is described, with which an accelerating voltage of $1^1/_4$ million volts is used, while the substance bombarded is at earth potential. The quantity of neutrons obtainable with this apparatus is approximately the same as could be produced with 5 kilograms of radium. At the end of the article various scientific and medical applications of the installation are discussed.

In recent years there has been a very rapid development of that branch of physics which deals with atomic nuclei. One of the most important pieces of apparatus for research in this subject and for practical applications which have already grown out of the investigations is the apparatus by means of which a very high velocity can be given to certain particles (ions), which are then used to bombard other particles. Two apparatus of this type, which were then called "neutron generators" because of their most important application, have already been described in this periodical[1]). The accelerating voltages were 300 and 600 kV respectively in those cases. In the case of the 300 kV neutron generator the yield of neutrons, although relatively large, was insufficient for many (particularly medical) purposes. The 600 kV apparatus has the disadvantage that the part where the transmutations take place was under high tension and the possibilities of its application were therefore limited. The yield of neutrons of the 600 kV generator was already considerably higher than that of the 300 kV generator, but further enlargement remained desirable.

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[1]) F. A. Heijn, The production and use of neutrons, Philips techn. Rev. 3, 331, 1938.

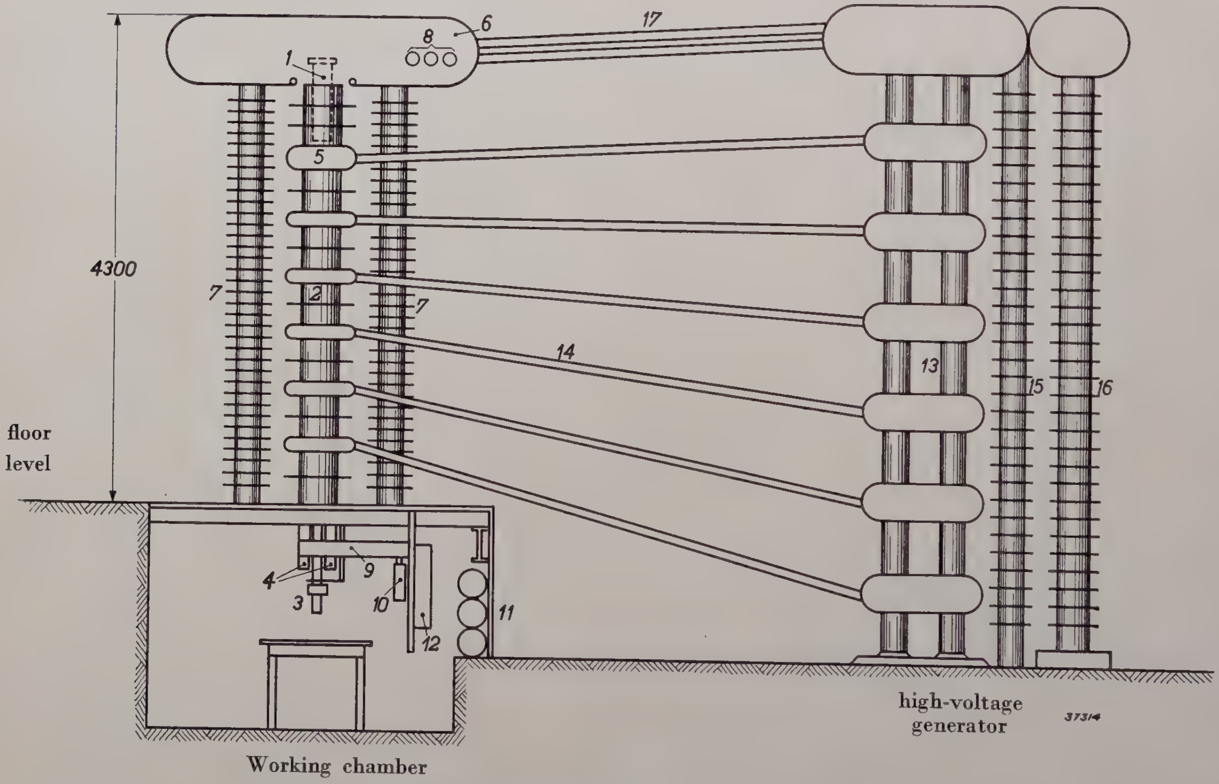

Fig. 1. Diagram of the whole apparatus. *1* source of ions, *2* acceleration tube, *3* arrangement for capture of the ions, *4* pumps, *5* flexible joint between the upper acceleration section, *6* shielding cap, *7* supporting columns for the cap, *8* manometer current and voltage meter for the ion source, *9* connecting tube between the pumps *4* and the preliminary pumps *10*, *11* buffers, *12* switchboard for the pumps, *13* high-voltage generator, *14* and *17* coupling resistances, *15* shunt condensers for the supply of the ion source, *16* cooled measuring resistance.

Therefore a start was made on the construction of a apparatus with an accelerating voltage of 1.25 million volts in which the transmutation chamber is earthed. In the following we shall give a description of this apparatus which is set up in the Philips laboratory, as well as several examples of its application.

Like the previous apparatus, the present one consists mainly of two parts: a tube in which the ions are produced and accelerated by a high voltage, and an installation for generating the necessary high voltage. *Fig. 1* is a diagram of the whole arrangement. Since the available room was not high enough for the high-voltage generator (the generator is about 5.80 m high, while. in order to prevent flashover, the ceiling must lie several metres above the top of the generator), it was placed in a pit about 1.30 m deep. The vertically placed tube is placed at floor level; beneath this tube is a chamber 3 × 3 m excavated to a depth of 2.50 m which can be entered by stairs at the side. In this chamber, in which the investigator can remain with safety while the apparatus is working, the transmutations take place. Entering and leaving the chamber is of course only possible when the high voltage is turned off. The switching desk for the operation of the apparatus is entirely outside the generator room. In this way the person who operates the apparatus is protected against X-rays and other radiation which may be excited at various points, while through several lead glass windows he can still have a good view of the room; moreover, he is in telephonic communication with the investigator in the transmutation chamber.

The tube

In fig. 1 the general construction of the tube may be seen. It contains a source of ions (1), in which the ions used for the transmutation are produced at a potential of 1.25 MV with respect to earth. The ions then "fall", accelerated by the potential difference through the acceleration tube *2*. In the lower section of the tube which projects through the floor into the laboratory below, the ions are captured by the substance which is to be transmuted (at *3*). In this chamber the pump installation (*4*) is also housed, which provides the required low pressure in the tube.

The ion source

It is only necessary to give a brief description of the source of the ions since it is practically the same as that of the previously described apparatus. *Fig. 2* shows a cross section of it. Between the chromium-plated copper anode cylinder *A* and the aluminium cathode cylinder *K* a voltage of 50 kV is applied. The whole is filled with the gas whose ions are to be used for the bombardment. In the space *S* a discharge then takes place, and the positive gas ions hereby formed can pass through the channel *k* drilled in the cathode to the outside, and so into the acceleration tube. Due to the special shape of cathode and anode, at not too high a pressure (0.02 mm Hg), a concentration of the discharge occurs in the neighbourhood of *k* so that a large percentage of the ions are available for acceleration. The anode must dissipate an energy of several kW; an oil-cooling system is therefore applied (oil lines *O*), about which we shall say more later.

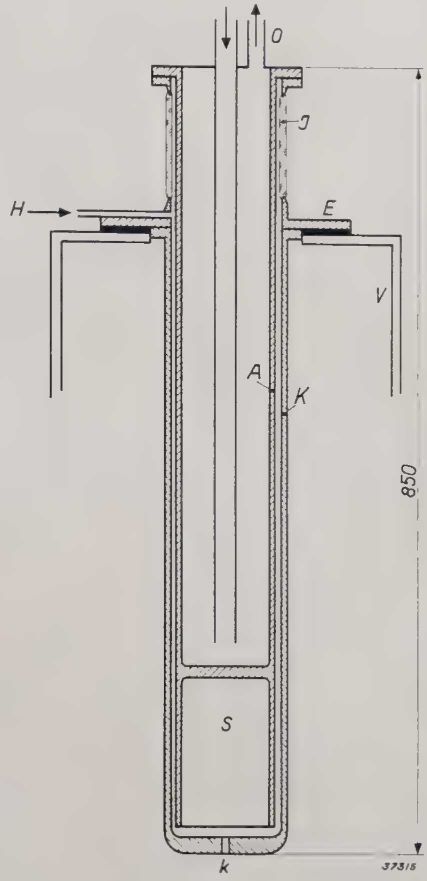

Fig. 2. Cross section of the ion source. *A* anode, *K* cathode, *S* discharge chamber, *k* channel through which the ions reach the acceleration tube, *O* lines for the oil cooling, *H* gas inlet, *I* insulating glass ring which is fastened by means of welded chrome iron flanges to *A* and *K*. With the flange *E* the ion source is fastened to the acceleration tube *V*.

The ion source, after being completely assembled, is inserted into the top of the acceleration tube with a rubber ring under the flange *E*. It is unnecessary to screw the flange tight, since after evacuation the air pressure holds the components firmly together; the rubber ring provides for a vacuum-tight seal.

The acceleration tube

The acceleration of the ions takes place in seven steps. The acceleration tube is subdivided into seven sections (see fig. 1) to each of which is applied $^1/_7$ of the total voltage, thus about 180 kV. In each section are two hollow tube-shaped electrodes (see *A* and *B* in *fig. 3*). The ions fly with a constant velocity through the one hollow electrode, are accelerated in the space between the electrodes with 180 kV, then, again with constant velocity, pass through the following tubular electrode, etc. This subdivision of the voltage is necessary in order to avoid too high a field strength, and thus cold electron emission at certain spots in the tube, while moreover the division of the tube into sections makes it possible everywhere to limit the distances covered by stray ions and electrons to such a degree that they can do no harm.

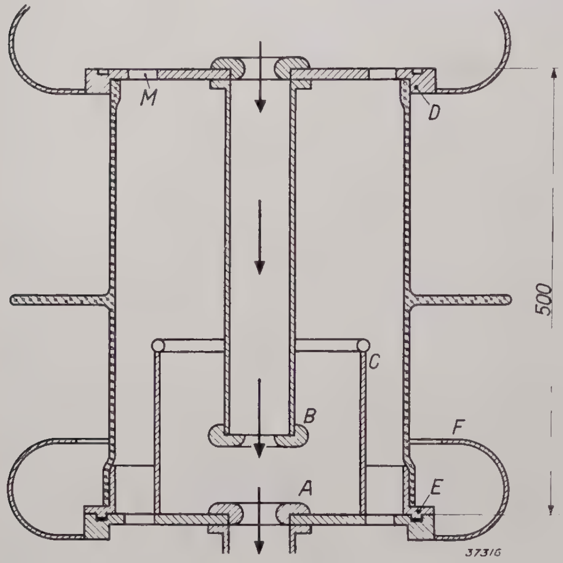

Fig. 3. One of the seven acceleration sections. *A* and *B* hollow electrodes through which the ions move and between which they are accelerated with 180 kV. *C* metal cylinder which surrounds the acceleration chamber. *D* and *E* metal flanges for piling the "Philite" cylinders on top of each other, *F* shielding caps for improving the form of the electric field, *M* holes in the transverse partitions for decreasing the flow resistance.

The sections consist of "Philite" cylinders which are provided with air-tight metal flanges (*D* and *E*). The electrodes are fastened to the flanges. The space between the electrodes of each section is further surrounded by a metal cylinder (*C*). This prevents the "Philite" wall from being struck by electrons which are freed from the cathode of each acceleration section by ions which strike them.

The complete sections are piled on top of each other with rubber rings between for the vacuum seal. Here also it is unnecessary for the sections to be screwed together, since they are pressed together by the air pressure with a force of 750 kg. In this way tubes for any desired acceleration voltage can be built up. Since the high-voltage generator is built on this sectional principle it is possible to begin with a small installation and to enlarge it later on for higher and higher voltages.

The flanges of the sections, set one upon the other, are surrounded by metal caps (*F*) in order to make the field vary more uniformly and to prevent corona discharge. To these caps the approximately 4 m long resistances are also connected *via* which the voltages are applied to the successive sections. The various details may be seen in the photograph *fig. 4*.

The arrangement for capturing the ions

The arrangement for capturing the ions below the tube is shown in *fig. 5*. After passing through the last acceleration section the ions pass through the tube *G*, the vacuum tap *K* and the glass intermediate section *H* (this and the insulation ring *I* in the ion source, see fig. 2, is the only glass which occurs in the whole tube), and finally reach the tube *T* at the bottom of which the actual disc for their capture is situated. This disc consists of the substance which is to be transmuted. Altogether, from the channel *k* in the ion source to the disc the ions cover a distance of about 4 m.Since in doing this they must pass through a large number of narrow tubes, namely the hollow electrodes, care must be taken that the beam of ions is directed exactly along the axis of the tube. The possibility of making this adjustment is obtained by making the joint between the first and second acceleration sections flexible (5 in fig. 1). By means of a simple mechanism operated from the underground laboratory by an insulating axle, the upper section with the ion source can be given the correct position while the tube is working. The adjustment can be controlled visually by observing the beam of ions on its way through the glass section *H*. In spite of the high vacuum the beam is visible here as a light streak because of its very great intensity. In order to be able to control the position and the cross section of the beam more accurately, a quartz plate is introduced into section *H*, which by means of a ground joint can be turned into the beam for a moment. At the spot where it is struck the quartz immediately becomes white-hot, and thus indicates the position of the beam.

Because of the considerable heat development due to the ion bombardment the disc *V* must be cooled by a rapid stream of water. The same is true of the tap *K* and other parts of th earrangement for

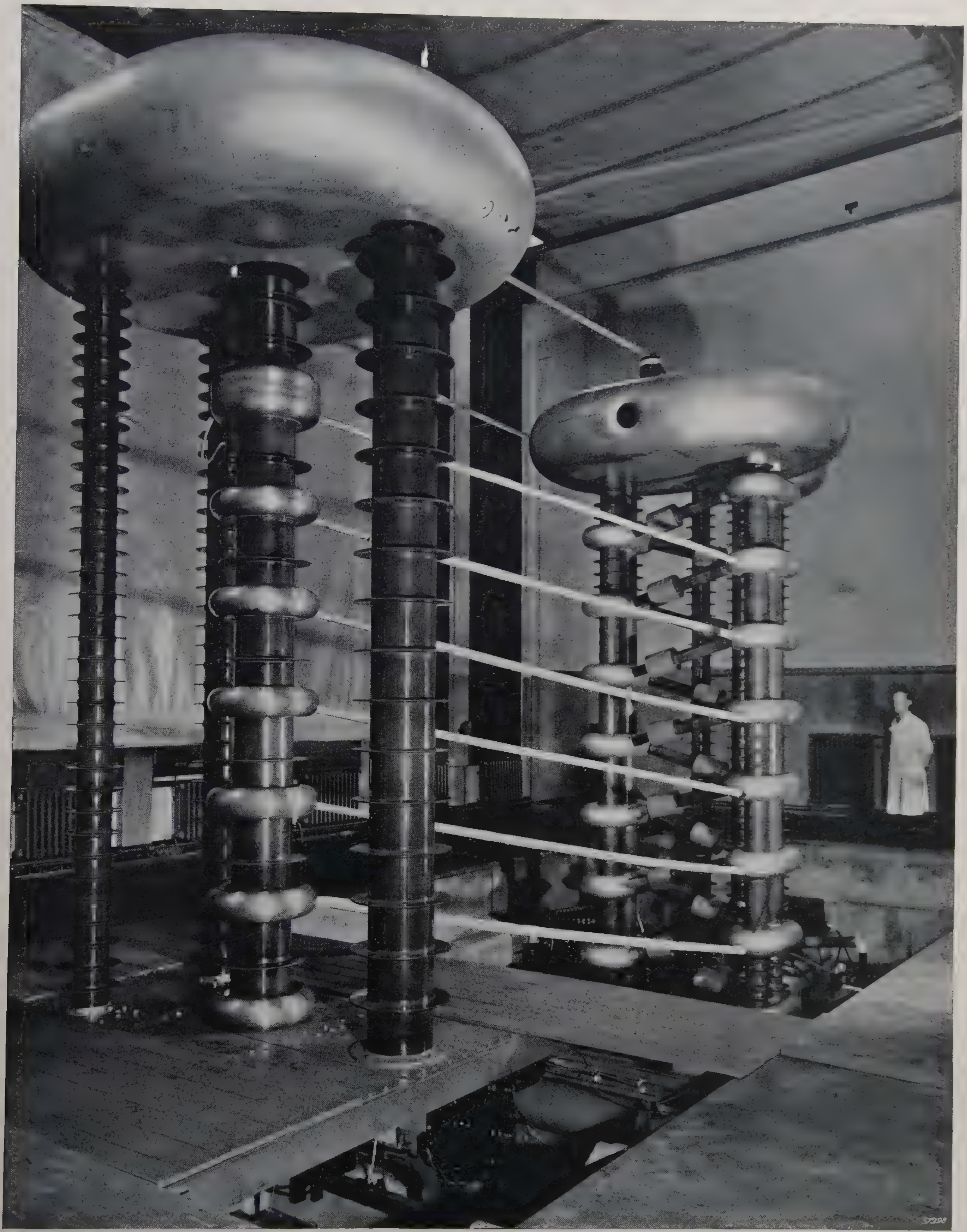

Fig. 4. View of the apparatus. In the foreground the 4 m long acceleration tube with three "Philite" supporting pillars for the shielding cap, and below, through the opening, the laboratory in which the transmutations take place. In the background the high-voltage generator whose successive stages are connected by approximately 4 m long resistances to the corresponding sections of the acceleration tube.

the capture of the ions which might be struck by scattered and reflected ions and thus become too hot (see the cooling spiral *L*). When the spot on the disc which is bombarded has become useless due to burning in or sputtering the whole arrangement can be shifted slightly, by means of a flexible connection (*I*) with the acceleration tube, so that the ions strike a different spot. For changing the disc, when for instance another substance is to be transmuted, the acceleration tube can be shut off with the tap *K*, so that no air enters it when the capturing device is opened.

Fig. 6 is a photograph of the laboratory in which the various details of the arrangement for capturing the ions can be seen.

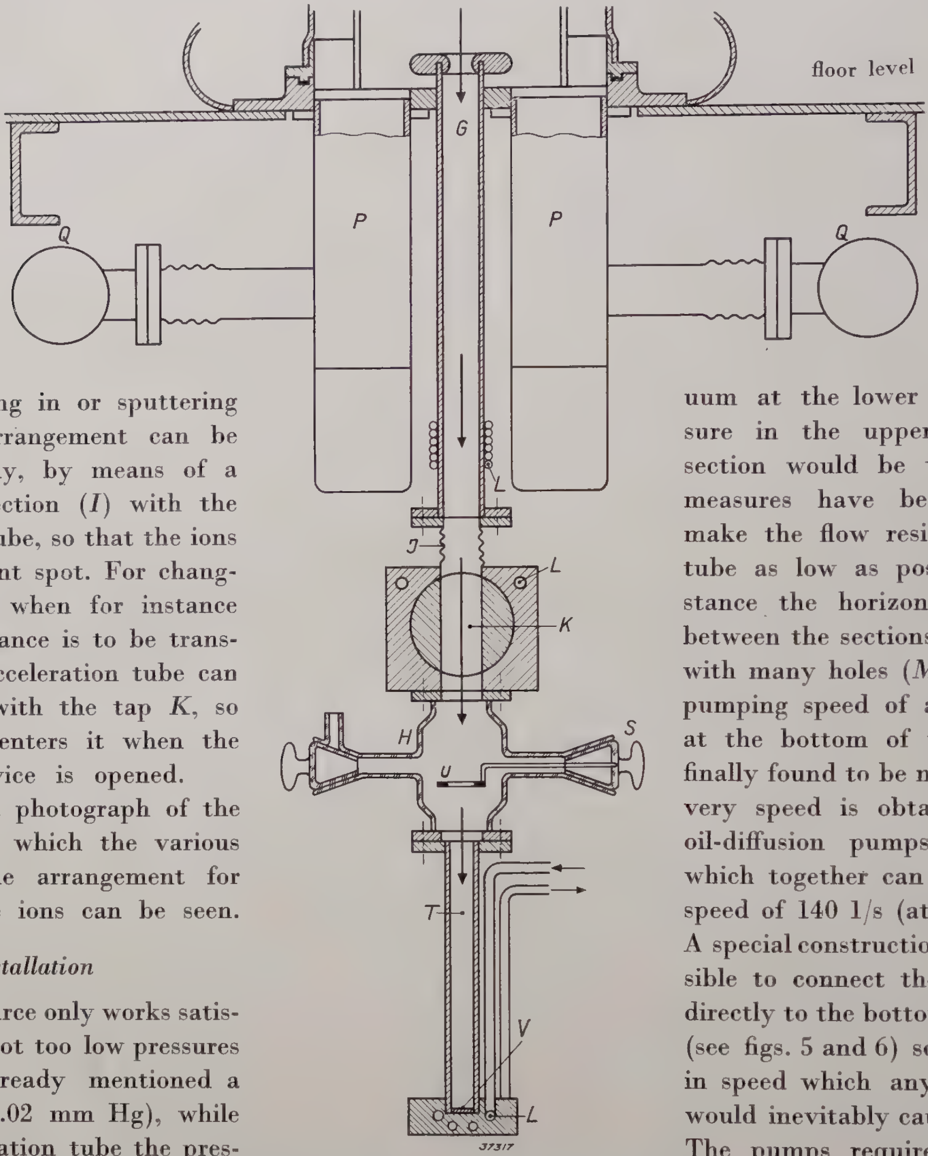

Fig. 5. The arrangement for capturing the ions. *G* last electrode tube at earth potential, through which the accelerated ions arrive, *I* flexible joint, *K* tap, *H* glass intermediate section, *S* ground glass joint by which the quartz plate *U* can be turned into and out of the ion beam, *V* disc for capturing the ions, *L* cooling spirals, *P* pumps, *Q* connection lines to the preliminary pumps.

The pump installation

The ion source only works satisfactorily at not too low pressures (we have already mentioned a pressure of 0.02 mm Hg), while in the acceleration tube the pressure must be as low as possible, preferably lower than 10^{-4} mm Hg. The difference in pressure between the two spaces which are connected by the chnanel *k* in the cathode of the ion source (fig. 2) can be maintained by vigorous pumping of the acceleration tube; the necessary pumping speed will be lower, the longer and narrower the channel *k*. This channel is, however, made fairly short and wide (5 mm long, 3 mm diameter) in order to enable the ions to leave the source easily and to obtain a high intensity of the ion beam. Therefore a very high speed of pumping was necessary. In addition, it is only possible to connect the pump to the earthed lower end of the 4 m long tube, and in spite of the great diameter of the tube (30 cm) a not inappreciable loss in speed may occur here. Even with an adequate vacuum at the lower end the pressure in the upper acceleration section would be too high. All measures have been taken to make the flow resistance of the tube as low as possible; for instance the horizontal partitions between the sections are provided with many holes (*M* in fig. 3). A pumping speed of about 100 l/s at the bottom of the tube was finally found to be necessary. This very speed is obtained by four oil-diffusion pumps in parallel, which together can even reach a speed of 140 l/s (at 10^{-4} mm Hg). A special construction made it possible to connect the four pumps directly to the bottom of the tube (see figs. 5 and 6) so that the loss in speed which any vacuum line would inevitably cause is avoided. The pumps require a fore vacuum of 10^{-3} mm Hg, which is obtained for each two high-vacuum pumps by one oil-diffusion pump of smaller dimensions. These two preliminary pumps in turn require a fore-vacuum (about 0.2 mm Hg) which is provided by one rotating pump of the ordinary construction. The connections (*Q* in fig. 5) between high-vacuum and fore-vacuum pumps must have a large diameter (10 cm) in order to avoid speed losses here also. Furthermore buffers are introduced between the various pumps in order to ensure a more stable functioning.

The vacuum is continually controlled from the switching table by means of a Philips vacuum meter [2]), while moreover a safety device provides that defects in the pumping system are immediately indicated by lamps on the switching table. This is very important since a lowering of the vacuum may cause a breakdown in the tube which may result in serious damage with the high-voltage used.

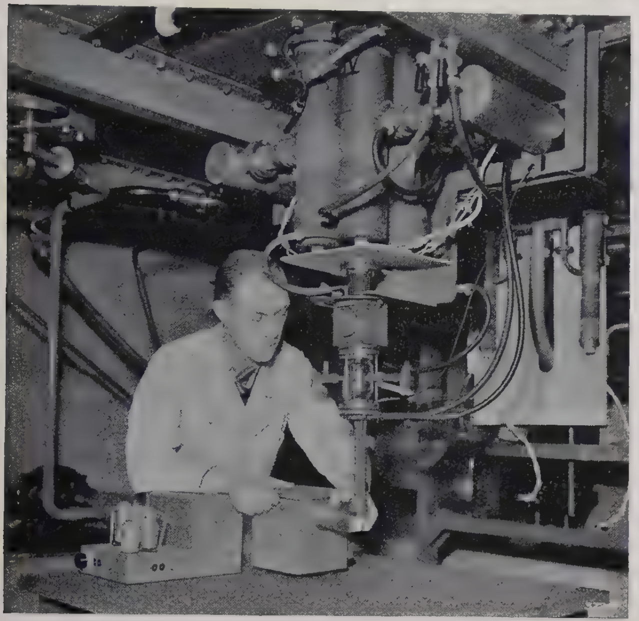

Fig. 6. The laboratory in which the transmutations take place. The glass intermediate section in the arrangement for capturing the ions may be seen, and beneath it the tube at whose end the disc of the substance to be transmuted is placed. Above may be seen the four oil-diffusion pumps grouped around the tube. On the table is a counting apparatus with which for example the intensity of the neutrons radiation obtained can be determined.

Other details

Above the tube is a broad metal shielding cap which is supported by three "Philite" columus (clearly visible in fig. 4), and which fulfils several functions. In the first place it serves to prevent the distortion of the electric field along the tube under the influence of the ceiling, etc. By means of the large radius of curvature of the cap (the smallest radius of curvature occurring is 30 cm) and by smooth finish of the surface the occurrence of of corona discharge is prevented. Furthermore various auxiliary apparatus are housed inside the cap, namely bulbs with supplies of gas for the ion source, a 50 kV rectifier for the supply of the ion source, and parts of the cooling system of the ion source. As to the gas used, most work is done with ions of hydrogen or of deuterium (so-called heavy hydrogen). The necessary gas flows from the bulb in question *via* an adjustable valve into the ion source. According as the pressure in the supply bulb falls, the valve must be opened wider in order to maintain the required pressure in the ion source. Since this adjustment must be able to take place while the apparatus is under high tension, an axle of pertinax for turning the valve is mounted in one of the three "Philite" columns mentioned. This axle is driven by a motor from below which is operated from the switch table. From here also the manometer can be read which is situated in a compartment in the shielding cap (see figs. 1 and 4) and which indicates the pressure in the supply bulb. In two other compartments of the cap are current and voltage meters of the rectifier for the ion source.

The cooling of the anode of the ion source takes place with oil due to the required state of insulation. This oil is let in and out *via* pertinax pipes through the second and third "Philite" columns and *via* a reservoir situated in the cap. Two branches also carry oil to the flange *E* of the source (see fig. 2) and to the flexible joint in the tube (5 in fig. 1). The oil itself, after its return to earth potential, is cooled by a spiral with water circulation.

It is striking that, apart from the electrical connection and the cooling pipes which are both flexible, the acceleration tube stands entirely free of the shielding cap. This was necessary because, as we have seen, the upper acceleration section must be able to be directed. In spite the small area of the base upon which the 4 m long tube rests, it stands sufficiently firmly because of the air pressure. A rigid mechanical connection with the cap would be undesirable because of the need of being able to assemble the tube easily, and moreover upon vibration of the heavy shielding cap it would be accompanied by the danger of cracks in the tube wall.

The high-voltage installation

The D.C. voltage of $1^1/_4$ million volts used for the acceleration of the ions is obtained with a cascade generator such as has already been described in this periodical [3]). In this case it was built up of seven stages which may be seen in figs. 1 and 4, and whose voltages correspond to the values which are necessary for the seven sections of the acceleration tube. The seven generator stages are connected to the different sections *via* the resistances already mentioned; in this way a potentiometer for 1.25 MV is not needed to distribute the voltage uniformly along the acceleration tube.

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[2]) F. M. Penning, Philips techn. Rev. 2, 201, 1937.

[3]) A. Kuntke, A generator for very high direct current voltage, Philips techn. Rev. 2, 161, 1937.

A separate problem is presented by the alternating current supply of the 50 kV rectifier for the ion source at a potential of 1.25 MV with respect to earth. The problem is here solved in the same way as described in the article referred to [1]); the A.C. voltage is applied *via* two condensers (*15* in fig. 1) and two resistances (*17*). These condensers for a *D.C.* voltage of 1.25 MV may well be considered unique. In order to be able to make them of reasonable dimensions an A.C. voltage of 500 c/s was used for the supply instead of the usual 50 c/s; a capacity of 3 000 cm is thereby sufficient.

The source voltage, like the acceleration voltage can easily be regulated at the switching table with this system. The latter voltage is measured with a mA-meter in series with an oil-cooled resistance (*16* in fig. 1). The mA-meter is calibrated directly in kV.

In the photograph fig. 4 a paper screen may be seen above and behind the apparatus. This becomes charged to about half the voltage (600 kV). By this means the field strength at caps and resistances is limited, so that there is less chance of corona discharge and flashover.

Results and examples of application

The apparatus is most commonly used for the production of neutrons [4]). The capture disc for this purpose is made of lithium and is bombarded with deuterium ions, whereby the lithium atoms are converted into two helium atoms and a neutron, according to the reaction equation:

$$\mathrm{Li} + \mathrm{d} \rightarrow 2\,\mathrm{He} + \mathrm{n}$$

The number of neutrons which can be produced with this apparatus amounts to about 10^{11} per second. It is customary to compare this yield with that obtained upon bombarding beryllium with the α-particles of radium. In that case the following reaction takes place:

$$\mathrm{Be} + \alpha \rightarrow \mathrm{C} + \mathrm{n},$$

and 1 mg. radium produces in this way about 20 000 neutrons per second. In order to obtain as many neutrons as with the apparatus described, therefore, about 5 kg radium would be needed! This is much more than exists (purified) in the whole world. For the sake of comparison it may be stated that the previously described 300 and 600 kV installations were equivalent in this respect to about 20 and 300 g radium, respectively.

The neutrons have a similar action upon tissues as X-rays and can therefore, like the latter, be used for therapeutic purposes (such as the cure of cancer) and for all kinds of biological experiments (such as the causing of mutations). Important results have already been obtained in this field. Usually, however, the neutrons are used for the preparation of artificial radioactive substances. Most elements can be converted into radioactive products by irradiation with neutrons. These products are not only of scientific interest, but have also attained great practical importance, again particularly in medicine. For this purpose much radioactive phosphorus has been prepared in recent times with the apparatus described. The following method is used. Around the disc for capture (which is introduced for this purpose into a long narrow tube, *T* in fig. 5) a vessel containing carbon disulphide is placed, while between the disc and the wall of the vessel a voltage of several thousand volts is applied. The neutrons produced on the disc and leaving the tube in all directions transmute the sulphur atoms according to the equation:

$$\mathrm{S} + \mathrm{n} \rightarrow \mathrm{P} + \mathrm{H},$$

whereby the phosphorus atoms formed are radioactive with a half-value time (*i.e.* the time in which the radioactivity has fallen to one half) of 14 days. Moreover these phosphorus atoms are ionized upon formation, and are therefore drawn to the wall by the electric field in the carbon disulphide. Here the phosphorus is deposited in the form of phosphates by a chemical treatment, and it can then be sent to the various medical and other institutions. In this way a number of institutions in the Netherlands as well as in Belgium, Denmark and Italy are provided with radioactive phosphorus. The samples obtained have already been succesfully used for the treatment of leuchaemia patients. The radioactive phosphorus behaves chemically exactly like ordinary phosphorus, and like the latter, when injected subcutaneously, it goes chiefly to the bone marrow, *i.e.* the seat of the disease in leuchaemia [5]).

Due to their property of behaving chemically exactly the same as the corresponding non-radioactive elements, the activated substances are also very suitable as indicators in chemical and biological experiments. One then has as it were a number of "tagged" atoms (*i.e.* detectable by their radioactivity), whose adventures among large quantities of the same element or compounds of it can be continually followed. If for exemple the end of a gut twig of some plant is placed in a phosphate solution in which there is also a trace of radioactive phosphorus, several hours later the exchange of phosphorus between the plant and the solution can be demonstrated by the fact that the leaves on the twig have become radioactive! This method is also suitable for quantitative investigations, as may be seen from numerous publications [6]).

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[4]) On the subject of neutrons in general see the article referred to in footnote [1]) and also, W. de Groot, Nuclear physics, Philips techn. Rev. **2**, 97, 1937.

[5]) It may here be noted that the relatively short half-value time of the artificial radioactive substances is essential for the medical application described. Upon injection of radium-containing substances, for example, whose activity practically does not decrease due to the long half-value time (1550 years in the case of radium), the patient would be exposed to a permanent irradiation which in the end would also destroy the healthy tissue.

In addition to all these application in which the transmutations brought about with the apparatus are only a means to an end, the apparatus also makes possible fruitful investigations of the transmutation itself. Lithium may be bombarded with ordinary hydrogen (instead of heavy hydrogen) and X-rays of great hardness are excited. In order to obtain these rays in the ordinary way with an X-ray tube, one would need an X-ray tube for 17 million volts (which does not exist of course), while for the hardest γ-rays of radium 2.5 million would "already" be sufficient. Such hard rays have very remarkable properties; for example they are not absorbed in matter like ordinary X-rays and γ-rays by giving off energy to electrons and atoms, but by so-called materialization, in which each quantum of the radiation passes over into a positive and a negative electron.

One very remarkable transmutation which was investigated with the apparatus [7]) is the fision of uranium and thorium. These elements fall apart upon bombardment with neutrons and enormous quantities of energy are liberated (corresponding to the energy which an electron would have after passing through a potential difference of 100 million volts). The fragments which are hereby formed could be separated and examined after the bombardment, thanks to the high concentration in which they were formed with this apparatus: they were found to consist of the rare gases xenon and krypton, among other products, and these in a radioactive form. By further fision ceasium, rubidium and barium are formed from them.

It is true that the amounts of the transmuted substances obtained are still extremely small from the chemical point of view and only in exceptional cases could they be detected with a balance. Nevertheless it may be stated that at least in principle the dream of the alchemists has come true.

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[6]) See for example: A. H. W. Aten, Isotopes and the formation of milk and eggs, Diss. Utrecht 1939.

[7]) A. H. W. Aten, C. J. Bakker and F. A. Heijn, Nature London, **143,** 516 and 679, 1939.

A DIRECT CURRENT SUPPLY APPARATUS WITH STABILIZED VOLTAGE

by H. J. LINDENHOVIUS and H. RINIA.

621.396.682 : 621.316.722

By means of amplifier valves it is possible to stabilize very effectively the output voltage of a plate voltage apparatus, so that it is scarcely affected by variations of the mains voltage or of the current taken off. A direct current supply apparatus with stabilized voltage (GM 4 560) developed by Philips is described. The output voltage of this apparatus is variable between 150 and 300 volts; the current taken off may amount to 100 mA. With the mains voltage fluctuations occurring the output voltage varies less than 0.004 per cent of the value chosen. The internal resistance under most conditions is less than 1 ohm, and under all conditions less than 4 ohms.

For many purposes in factories and laboratories a source of direct current is required with a constant terminals voltage which is independent of the current taken from the source. An example of a current source which is capable of satisfying these requirements is formed by the accumulator battery which is indeed used with success in many cases as a source of constant voltage. In recent times, however, a more and more serious attempt may be observed to replace the accumulator batteries by the much lighter plate voltage apparatus which requires much less maintenance. This is true particularly when the source of current must have a voltage of several hundred volts and at the same time need give only a relatively small current. If it is desired to realize such a current source by means of an accumulator battery, a large number of cells must be connected in series, so that even with fairly small cells a large and heavy combination is obtained, while, moreover, such a battery has a relatively large internal resistance and therefore only approximately satisfies the requirement that the voltage shall be independent of the current taken off.

If instead of the accumulator battery the familiar plate-voltage apparatus is used, consisting of transformer, rectifier and a filter for smoothing the ripple of the rectified A.C. voltage, the purpose in view is likewise not achieved. Not only does this apparatus possess a considerable internal resistance so that the output voltage is quite appreciably dependent on the current taken off, but also the output voltage fluctuates in the same relation as the voltage of the mains with which the apparatus is connected. Mains voltage fluctuations of 5 per cent are not in the least unusual so that there can be no question of a constant output voltage.

This objection can be met by connecting one or more neon stabilizer tubes between the output terminals of the plate-voltage apparatus. The output voltage is then indeed much less closely dependent upon the mains voltage; the internal resistance, which in this case is practically equal to the differential resistance of the stabilizer tubes, still, however, amounts to from 50 to several hundred ohms.

In this article we shall discuss several automatically working regulatory arrangements which make it possible to keep the output voltage of a plate-voltage apparatus constant within very narrow limits. It will be found that with relatively simple means it is possible to eliminate entirely both the voltage variations due to the changes in the current taken off and those caused by fluctuations in the mains voltage. A direct current supply apparatus with stabilized voltage which has been constructed will be described, which, apart from the perfect constancy of the voltage, also has the advantage over the accumulator battery that its voltage can be varied continuously.

The regulation principle

In principle a constant voltage can be obtained by including in series with an ordinary supply apparatus, for example, a non-regulated plate-voltage apparatus, a resistance which automatically becomes larger when the output voltage has the tendency to increase due to an increase in the mains voltage or to a decrease in the current. With the opposite tendency the resistance must become smaller. This can be obtained by using as resistance a triode whose control-grid voltage is made dependent in a suitable manner on the difference between the output voltage V_u and a constant comparison voltage V_b. This comparison voltage may for example be obtained with the help of a dry battery. If the connections are so arranged that the source need not furnish any current for the comparison voltage, it is not difficult to keep this voltage constant.

A simple example of such a regulatory connection is indicated in *fig. 1*. An ordinary plate-voltage apparatus is connected to the left-hand terminals. the voltage is taken from the right-hand terminals. The grid of the triode is connected to the positive pole of a dry battery, whose negative pole is connected to the negative output terminal.

The output voltage V_u will adjust itself at a slightly higher value than that of the battery, and in such a way that the grid of the triode possesses exactly the negative voltage with respect to the cathode which is necessary to transmit the current i to be furnished externally. If we now increase the input voltage V_i and thus the plate voltage of the triode, while we leave the current given off unaltered, then the voltage V_u will also increase slightly, and to such a degree that the increase of the negative grid voltage which occurs as a result just compensates the effect of the plate-voltage increase on the triode current. Since a slight change in grid voltage is able to nullify the effect of a large change in plate voltage, the variation in output voltage caused is only a fraction of the variation of the input voltage. In the following we shall call the following ratio:

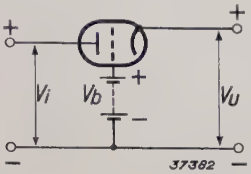

Fig. 1. Circuit diagram showing the principle of the stabilization of a voltage. If the input voltage V_i rises while the current given off is kept constant, the output voltage V_u rises only slightly since the increase of the negative grid voltage occurring as a result need only be small to compensate the influence of the plate voltage increase which results from the input voltage increase. If the current given off i increases while the input voltage is left unchanged, the output voltage falls only slightly, since the decrease of the negative grid voltage occurring as a result need only be small to increase the current i by the desired amount.

$$\left(\frac{\Delta V_u}{\Delta V_i}\right)_{\Delta i = 0}$$

the attenuation factor a.

If we increase the current given off while leaving the input voltage unchanged, the output voltage will fall somewhat; as a result the grid voltage of the triode becomes somewhat less negative, as much as is necessary to increase the triode current by the desired amount.

The ratio

$$\left(-\frac{\Delta V_u}{\Delta i}\right)_{\Delta V_i = 0}$$

is called the internal resistance R_i of the regulatory connections, as usual.

We now wish to determine a and R_i quantitatively and we begin with the familiar relation

$$\Delta i = S\,\Delta V_g + \frac{S}{\mu}\,\Delta V_a, \quad . \; . \; . \; . \quad (1)$$

which gives the relation between variations in the grid voltage V_g, the plate voltage V_a and the plate current i, and in which S is the slope and μ the amplification factor. For our case i is also the current given off and the following is true:

$\Delta V_g = -\Delta V_u$; $\Delta V_a = \Delta V_i - \Delta V_u$, and therefore

$$\Delta i = -S\left(1 + \frac{1}{\mu}\right)\Delta V_u + \frac{S}{\mu}\,\Delta V_i \, . \; . \; . \quad (1a)$$

From this it is easily derived that:

$$a = \left(\frac{\Delta V_u}{\Delta V_i}\right)_{\Delta i = 0} = \frac{1}{\mu + 1} \; . \; . \; . \quad (2)$$

and $$R_i = \left(-\frac{\Delta V_u}{\Delta i}\right)_{\Delta V_i = 0} = \frac{\mu}{S\,(\mu + 1)} \; . \quad (3)$$

By approximation therefore $a = 1/\mu$ and $R_i = 1/S$.

From (1a) follows also the attenuation which occurs for the case when the apparatus is loaded with a constant external resistance R_u. Then instead of $\Delta i = 0$ we have $\Delta i = \Delta V_u / R_u$. The result is:

$$\frac{\Delta V_u}{\Delta V_i} = \frac{1}{\mu + 1 + \dfrac{\mu}{R_u S}} \, .$$

We must also discover what value is assumed by the internal resistance in the case when the supply apparatus itself which produces the voltage V_i possesses an internal resistance of R_v; then ΔV_i is not equal to zero, but $\Delta V_i = -R_v \Delta i$ and we find that:

$$R_{\text{total}} = \frac{\mu}{S\,(\mu + 1)} + \frac{R_v}{\mu + 1} \; . \; . \; . \; . \quad (4)$$

If we compare (4) with (3) we see that the internal resistance is increased by an amount $R_v/(\mu + 1)$. This is clear since an input voltage change of $R_v \Delta i$ according to (2) leads to an output voltage change of $R_v \Delta i/(\mu + 1)$.

In order to obtain an idea of the usual order of magnitude we may fill in in the above formulae: $\mu = 20$, $S = 10$ mA/V and $R_v = 500$ ohms. Formula (3) then gives for a the value 0.048, and formula (4) for the total internal resistance $95 + 24 = 119$ ohms.

Several possibilities of improvement

Continuous adjustment of the voltage

As we have seen above the output voltage adjusts itself at a value slightly higher than that of the battery. The output voltage may thus be altered by changing the voltage of the battery. This can be done by putting more or less cells into connection. The voltage change can then naturally only occur in steps. For a continuous regulation we could introduce a potentiometer across one or more cells; this means, however, a load on the battery which in the course of time will result in an appreciable fall in voltage.

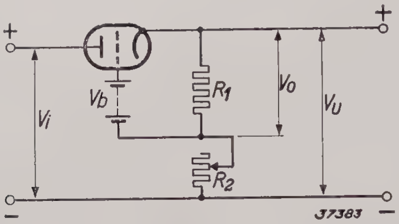

Fig. 2. By not connecting the control grid *via* the battery to the negative output terminal, but to the tap of a potentiometer R_1, R_2, the output voltage is made continuously variable.

In *fig. 2* connections are given in which it is possible, without loading the battery, to regulate the voltage continuously. The negative pole of the battery is not connected with the negative output terminal but to a tap on a variable potentiometer which is introduced between the output terminals of the apparatus. It will be clear that everything which has been derived in the foregoing for the output voltage V_u now holds for the voltage V_0 over the resistance R_1 of the potentiometer. Between V_u and V_0 there is the following relation:

$$V_u = \left(1 + \frac{R_2}{R_1}\right) V_0 .$$

From this it follows in the first place that the output voltage is linearly dependent on the variable resistance R_2. Furthermore it is easy to see that a as well as R_i will be approximately proportional to V_u/V_0. Only the part

$$\frac{R_1}{R_1 + R_2}\,\Delta V_u = \frac{V_0}{V_u}\,\Delta V_u$$

of an output voltage variation ΔV_u acts on the grid of the triode. In order to influence the grid in the same way as in the connection of fig. 1, therefore, an output voltage variation which is V_u/V_0 times as large is required. The fluctuations of V_u occurring upon a given change of the input voltage or of the current taken off are therefore found in the first instance to increase by a factor V_u/V_0. From this we see, and this is also true for the following connection, that it is important not to choose the voltage V_0 and thus the battery voltage lower than is necessary in connection with the lowest output voltage which one desires to be able to obtain.

Improvement of the regulation with the help of a second amplifier valve

Although the connections described already lead in certain cases to satisfactory results, for very many applications it is desirable to be able to satisfy still higher requirements. Very considerable improvement can be attained by amplifying the fluctuations of the grid voltage of the regulatory valve with a second valve.

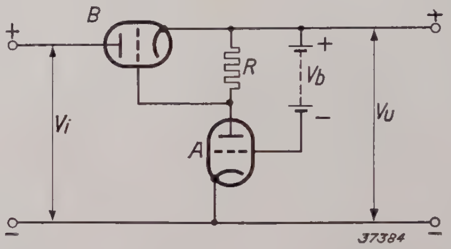

Fig. 3. Stabilizer connections with increased sensitivity. The voltage variations on the control grid of the regulatory valve B are amplified with the help of a second valve A.

In *fig. 3* the connections are given. When the output voltage rises by an amount ΔV_u the grid voltage of value A becomes higher (less negative) by the same amount; the plate current through R thereby rises, and if the amplification is n, the grid voltage of B will become more negative by an amount $n\Delta V_u$. From this it follows that we can immediately apply our previous results to this case if we only multiply the slope and the amplification factor by a factor n. By analogy with (2) and (4) one thus finds directly:

$$a = \frac{1}{n\,\mu + 1} \approx \frac{1}{n\mu}\,, \quad \ldots\ldots \quad (5)$$

$$R_{\text{total}} = \frac{\mu + R_v S}{S\,(n\mu + 1)} \approx \frac{1}{nS} + \frac{R_v}{n\mu} \quad \ldots \quad (6)$$

The constancy of the output voltage upon fluctuations of the mains voltage as well as upon fluctuations of the current taken off is therefore improved approximately by a factor n.

Application of a neon stabilization tube

There are still several objections to the connections of fig. 3 which will be made clear in the following. The voltage over the resistance R serves as negative grid voltage of B and varies from about 1 to 15 volts, according as the current given off by the apparatus is large or small. The plate current of A therefore also changes in the ratio 1 : 15, which is accompanied by the fact that (as a result of the curvature of the i_a-V_a characteristic) the slope of A, and therefore the amplification n, is very closely dependent upon the current given off by the apparatus.

This objection can be met by including a neon stabilization tube in the connection, as indicated in *fig. 4.* This tube is supplied through a resistance from the voltage source V_i. The resistance R is therefore connected to the positive electrode of the neon tube which has a working voltage of about 100 volts. As we have seen the grid of the valve B has a negative voltage of about 1 to 15 volts with respect to the cathode. It is therefore clear that the voltage over the resistance E in fig. 4 is about 100 volts higher than in fig. 3, and now varies from about 101 to 115 volts. The relative change is thus much less, the amplification n is therefore also much less closely dependent on the current given off by the apparatus. Moreover, the resistance R can be chosen much larger while retaining the same plate current and thus the same slope of A. The amplification will therefore not only be much more constant but also much higher [1]).

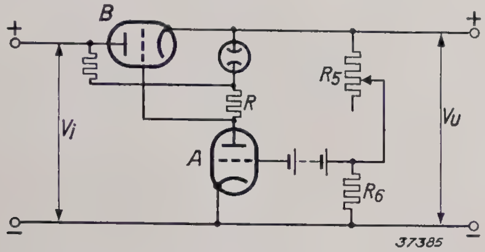

Fig. 4. By not connecting the resistance R of fig. 3 directly, but *via* a neon stabilizer tube, to the positive output terminal of the connections the fall in voltage along this resistance can be increased, and in this way a greater and more constant amplification of valve A can be obtained.

Since the amplification factor μ of valve B also depends only slightly upon the current given off, the attenuation factor α, which according to equation (5) amounts to about $1/n\mu$, is practically the same for all values of the current given off. This is true to a much smaller degree of the internal resistance, which according to equation (6) amounts to $1/nS + R_v/n\mu$: the slope of the valve B decreases as the plate current becomes smaller. The result is that the internal resistance becomes larger, the smaller the current given off.

If, in order to form an idea of the results attained, we assume that an amplification $n = 125$ is obtained with valve A, then with the values already used of $\mu = 20$, $S = 10$ mA/V (for valve B) and $R_v = 500$ ohms we find that:

$$\alpha = \frac{1}{2500} = 0{,}4\ {}^{0}\!/_{00},$$

$$R_{\text{total}} = 0{,}8 + 0{,}2 = 1{,}0 \text{ ohm}.$$

From this we see that by the use of the second amplifier valve and the stabilization tube we have obtained an improvement by a factor of 120.

The output voltage can be regulated continuously with the help of a potentiometer in a similar way as in the diagram of fig. 2. Here also the attenuation factor and the internal resistance are proportional to the ratio between output voltage and battery voltage. Since no current is taken from the tap of the potentiometer, the resistances R_5 and R_6 of the potentiometer can be chosen as large as desired, so that this potentiometer consumes very little extra energy. In practice, however, this is found to be unnecessary and even undesirable. If only little current is taken from the apparatus, the valve B must be heavily overbiased, and due to this the slope of this valve is very much lowered. It is better not to choose the resistances R_5 and R_6 too large so that the valve B never needs to deliver too small a current. The slope of this valve then remains greater and the values α and R_i then remain smaller and more constant.

Complete elimination of voltage variations

The principle followed in the connections described until now permits indeed a very sharp reduction of the voltage variations, but it is fundamentally impossible to attain a complete elimination of the voltage variations in the manner described. The amplifier valve A, and at the same time the valve B, are controlled by the output voltage; in order to bring the regulatory organ into action it is therefore fundamentally necessary that the output voltage should undergo a certain, although small change. By coupling the control grid of the amplifier valve not only with the output side but also with other points in the connections, however, it is possible to compensate the remaining voltage change, and if desired even to attain an over-compensation.

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[1]) It is possible to increase the voltage drop over the resistance R in another way, namely by connecting this resistance directly to the positive input voltage. If the input voltage rises, it is again necessary for good regulation that the grid voltage of B should become more negative. For this purpose, however, a much larger increase in the plate current of A is necessary in this case than in the connections with the neon tube. If in these latter connections we should keep the plate current of A constant, the grid voltage of B would also remain unchanged upon increasing input voltage, while in the other connections with constant plate current of A, the grid potential of B rises as much as the input voltage. The elimination of this rise in the grid potential requires an extra increase in the plate current of A. Further consideration shows that the change in the grid voltage of value A must in this case be a factor μ larger than in the connections with the neon tube. The regulation is therefore also poorer by a factor μ.

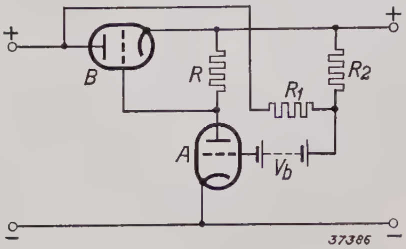

Fig. 5. Connections in which the output voltage remains absolutely constant upon a change in the input voltage.

Fig. 5 shows in what way the influence of a variation of the input voltage on the output voltage can be compensated. If it is desired that the output voltage and the output current flowing through the valve B should remain absolutely constant, while the input voltage varies by an amount ΔV_i, the control grid voltage of valve B must undergo an opposite change by an amount $\Delta V_g = \Delta V_i/\mu$. This change is n times as great as the change in the grid voltage of valve A, so that it must possess the value:

$$\Delta V_{g_A} = \frac{\Delta V_i}{n\mu} \quad . \; . \; . \; . \; . \; . \; . \quad (7)$$

Now V_{g_A} is equal to the output voltage, assumed to be absolutely constant, decreased by the likewise absolutely constant battery voltage and the voltage loss over the resistance R_2. The latter varies with the input voltage according to the relation:

$$\Delta V_{R_2} = \Delta V_i \frac{R_2}{R_1 + R_2}.$$

In order to satisfy equation (7) the resistances must be so chosen that

$$\frac{R_2}{R_1 + R_2} = \frac{1}{n\mu} \quad . \; . \; . \; . \; . \; . \; . \quad (8)$$

For $n = 125$, $\mu = 20$, this gives $R_1/R_2 = 2\,500$, thus for example $R_1 = 2.5$ megohms, $R_2 = 1\,000$ ohms.

Considering the fact that it is possible in this way to eliminate the voltage variations entirely, it might be asked why it is necessary to make n as large as possible. It would indeed be superfluous to do this if equation (8) could be exactly satisfied for all conditions of working. Since, however, even with the employment of the neon tube according to fig. 4, n as well as μ still vary somewhat with the current given off, this is impossible. Therefore for the majority of conditions of working a certain voltage variation remains which may be positive or negative, and is given approximately by:

$$\frac{\Delta V_u}{\Delta V_i} \approx \frac{1}{n\mu} - \frac{R_2}{R_1 + R_2}.$$

It is thus smaller, the larger the value of n.

If by satisfying equation (8) we have obtained a complete voltage compensation, then the part of the internal resistance which is due to R_v (equations (4) and (6)) also disappears. By a slight extension of the compensation connections, however, the remaining part of the internal resistance can also be exactly compensated. In *fig. 6* the connections are given. Let us consider a change in current Δi and again assume that the output voltage remains exactly constant. For the change in the control grid voltages of the valves B and A it then follows that

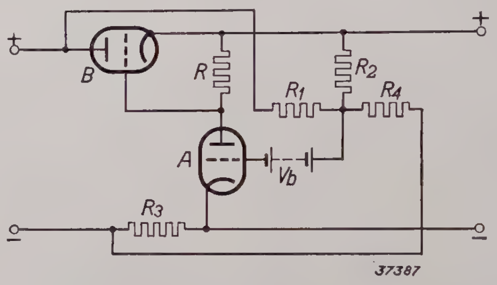

Fig. 6. Connections in which the output voltage remains absolutely constant upon a change in the current given off.

$$\Delta V_{g_B} = \frac{\Delta i}{S}, \text{ where } S \text{ is the slope of value } B, \text{ and}$$

$$\Delta V_{g_A} = \frac{1}{n} \Delta V_{g_B} = \frac{\Delta i}{nS} \quad . \; . \; . \; . \; . \quad (9)$$

By a correct choice of the resistances R_3 and R_4 the desired change in the control grid voltage of valve A can be obtained. The current variation causes over the resistance R_3 a voltage variation $R_3 \Delta i$, and of this the fraction $R_2/(R_2 + R_4)$ acts upon the control grid of the valve A. (It is hereby assumed that $R_1 \gg R_2$, which is always the case). By setting this equal to the value required according to equation (9), one obtains as condition for the disappearance of the internal resistance the relation

$$R_3 \cdot \frac{R_2}{R_2 + R_4} = \frac{1}{nS} \quad . \; . \; . \; . \; . \quad (10)$$

With $n = 125$, $S = 10$ mA/V, $R_2 = 1\,000$ ohms and R_4 for instance 50 000 ohms, we obtain $R_3 = 40$ ohms.

Since S changes quite rapidly with the current, and n also to a certain degree, equation (10) will only be exactly valid for a definite value of the current. In general there then remains a certain internal resistance which is given by:

$$R_{\text{total}} = \frac{1}{nS} - \frac{R_2}{R_2 + R_4} \cdot R_3 + R_v \left(\frac{1}{n\mu} - \frac{R_2}{R_1 + R_2} \right).$$

A difficulty now arises when we wish to make the voltage variable again. If this were done in the way indicated in *fig. 7* for voltage compensation, the degree of compensation would depend upon the voltage chosen. The part of the input voltage variation ΔV_i which acts on the grid of A is determined by the relation of R_1 to the connection in parallel of R_5 and R_6 [2]), and is therefore dependent on R_5. The result would be that when the compensation is correct at low output voltage, there would be over-compensation at high output voltage, *i.e.* there would be a decrease of output voltage upon an increase of input voltage. The same difficulty occurs to the same degree in the compensation of the internal resistance.

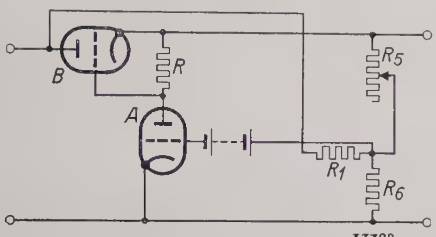

Fig. 7. Connections in which the voltage compensation according to fig. 5 is combined with the variability according to fig. 4. One objection is that the fraction of the input voltage change which acts on the grid of valve A depends upon the value of the resistance R_5 and therefore upon the output voltage chosen.

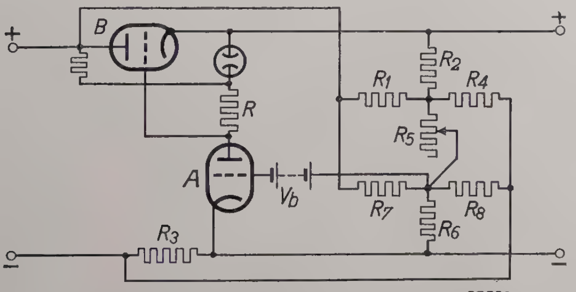

Fig. 8. Connections in which the compensations according to figs. 5 and 6 are combined with the variability according to fig. 4. By means of a bridge connection the disadvantage of the connections of fig. 7 is eliminated.

It is possible, however, with the help of a bridge connection to avoid these difficulties. In the diagram of the complete connections *fig. 8*, this is shown for voltage compensation as well as for compensation of the internal resistance. The bridge connections from this figure are given separately in *fig. 9* for the sake of clearness.

The resistances R_1, R_2, R_6 and R_7 form a Wheatstone bridge in which R_5 is the diagonal. It is immediately clear that the fraction of ΔV_i which acts on the grid of valve A is independent of the resistance R_5 if the following condition is satisfied:

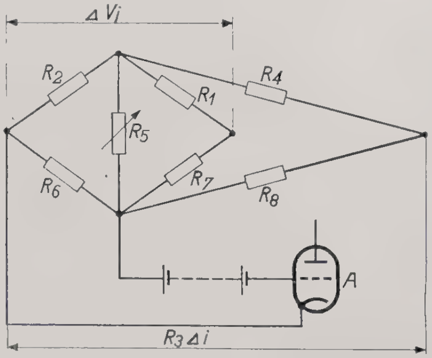

Fig. 9. Diagram of the bridge connections of fig. 8.

$$R_1 : R_2 = R_7 : R_6.$$

If, in addition, in agreement with equation (8), we make this ratio equal to $n\mu - 1$, the condition for compensation is satisfied at the same time. We have thus succeeded in obtaining the correct voltage compensation for all values of the voltage chosen independent of the magnitude of the resistance R_5.

The same holds for the compensation of the internal resistance. Here the bridge is formed by the resistance R_4, R_2, R_6 and R_8, with R_5 again as diagonal. If again

$$R_4 : R_2 = R_8 : R_6$$

and moreover if, according to equation (10), this ratio is equal to $nSR_3 - 1$, then the compensation of the internal resistance is also correct for all values of the voltage chosen.

The internal resistance for alternating currents

It will often occur that the apparatus, besides direct current, will have to deliver alternating current as well, for instance when it is used as source of supply for an alternating current amplifier. In that case it may be of great importance (for example in order to avoid undesired couplings in amplifiers) that the A.C. voltages thereby occurring at the output terminals should be small; in other words the "internal impedance" for alternating current should be low.

How does this "internal impedance" occur? We have seen that the internal resistance depends upon the amplification n of valve A. With increasing frequency this will now decrease due to the capacity C_0 which inevitably acts over the resistance R. The result will be that the internal resistance increases with higher frequencies. It is as if, in series with the internal resistance for direct current R_i, there were an "internal self-induction" L_i. A simple calculation shows that

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[2]) Since we assume that no voltage variations occur between output terminals, in the investigation of the behaviour of the connections with respect to voltage variations we may consider these terminals as mutually connected.

$$L_i = \frac{V_u}{V_0} \cdot \frac{RC_0}{nS} \, .$$

The order of magnitude of L_i is several microhenries.

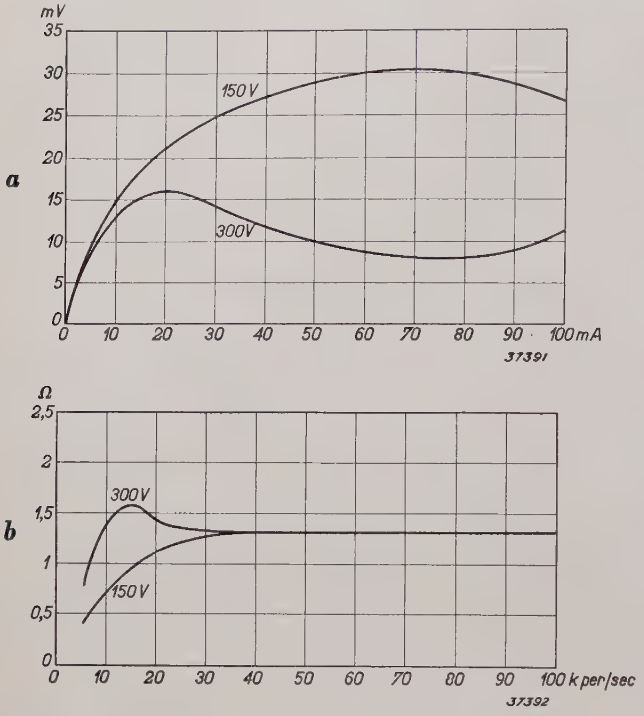

Fig. 10. Diagrams of the direct current supply apparatus GM 4 560.
a) Change in the output voltage as a function of the current given off.
b) Internal impedance as a function of the frequency.

In order to prevent the internal impedance of the apparatus from becoming too high at high frequencies, electrolytic condensers are placed across the output terminals. Then for the case where the internal resistance for direct current is reduced to zero in the way described, the internal impedance consists of a loss-free self-induction in parallel with the electrolytic condensers. If we plot the internal impedance against the frequency, we obtain a resonance curve which, however, is found to be very much damped because of the series resistance of the condensers. By the choice of the capacity and the series resistance we are still able to influence the shape of the resonance curve (the frequency characteristic) to a large extent.

Construction of the apparatus

In the apparatus as constructed (type GM 4 560) the output voltage may be varied continuously between 150 and 300 volts. As comparison voltage

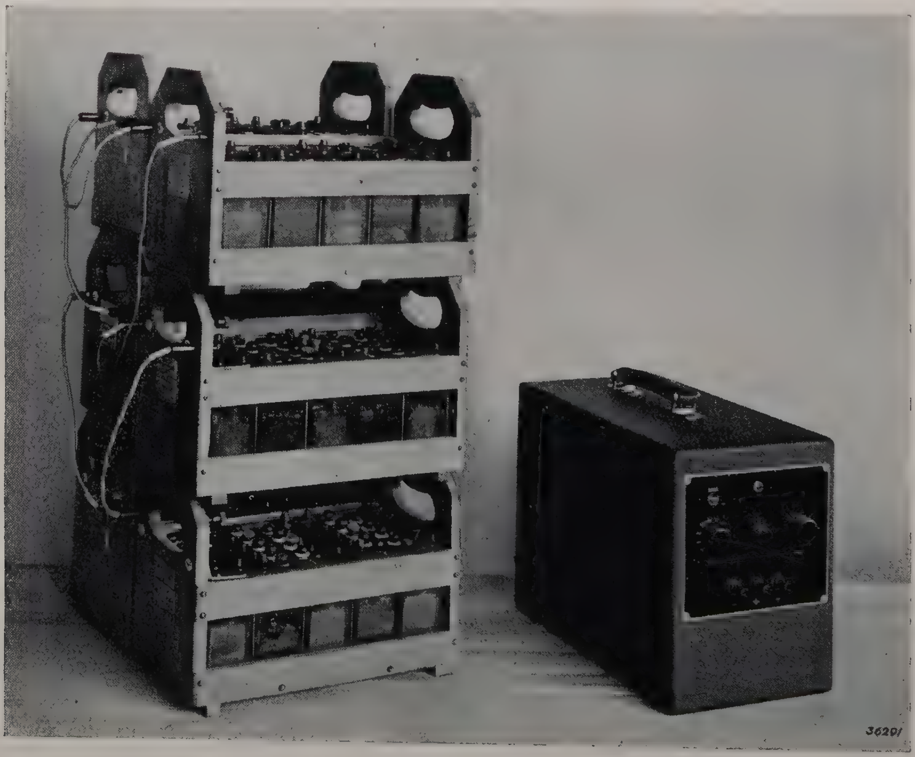

Fig. 11. The direct current supply apparatus compared with an accumulator battery of the same voltage and corresponding output.

a dry battery of 120 volts is used. The maximum current is 100 mA.

A mains voltage variation of 5 per cent causes an output voltage variation of less than 0.004 per cent of the value chosen. The change in the output voltage under the influence of the load is shown in *fig. 10a* for two different output voltages. The slope of this characteristic gives the internal resistance. For currents greater than 30 mA this is found to be a maximum of 0.5 ohm at an adjustment on 150 volts, and 1 ohm maximum at an adjustment on 300 volts. For currents smaller than 30 mA the internal resistance may amount to four times these values.

In fig. 10*b* it is shown for two different values of the output voltage how the internal impedance of the apparatus depends upon the frequency. It may be seen that it is smaller than 1.6 ohms for all frequencies. The fact that at 100 kc/s the impedance still amounts to more than 1 ohm may be ascribed to the series resistance of the electrolytic condensers. At still higher frequencies the impedance is smaller due to the fact that in parallel with the electrolytic condensers a paper condenser is introduced whose series resistance is many times smaller.

The dimensions of the whole apparatus, which is composed of a plate voltage apparatus and the regulatory organ described, are 20×43×31 cm. The weight is about 19 kg. In this weight is included that of the battery (2.5 kg) which will hardly ever need to be renewed in the course of one year. *Fig. 11* shows the exterior of the apparatus; for the sake of comparison an accumulator battery is also shown which gives about the same power at the same voltage. Weight and volume of the battery are about three times as great.

THE CONTROL OF CONTACT PRESSURES

by W. WERNER

621.3.066.6

For the satisfactory functioning of switches, contact springs, etc. it is necessary that the contact pressure should lie between certain limits: at too low a pressure the transition resistance becomes too great and the contact spots may become too hot, at too high a pressure a too rapid wearing off may occur upon repeated closing of the contact. For each case the permissible limits of the contact pressure can best be determined experimentally. For example, for a certain type of mains switches which are used in radio receiving sets, it was found that the contact pressure must lie between 60 and 120 g.

In the mass production of these switches the question arose, as to how it is possible to find out rapidly and simply whether the individual product satisfies the requirement given above. For the determination of pressures of springs several methods are known. In the case in question, however, a particularly simple solution could be found which was specially adapted to the methods of mass production, by making use of the switching action of the contact to be tested itself. The principle of the method is represented in *figs. 1* and *2*. In fig. 1*c* is the switch to be tested (diagrammatic), *a* and *b* are two adjustable auxiliary contacts. In the initial state *a* and *c* are closed, and *b* open. When the lower contact strip of *c* is pulled down, there is a conflict between the elasticity of the springs k_1 and k_2 (to which the contact pressures of *c* and *a*, respectively are proportional). If k_1 is much weaker than k_2 then, upon pulling, at a certain moment the contact *c* will open; if pulled farther, at a certain extension of the spring k_1, its force will be large enough to overcome the pull of k_2 so that the contact *a* is then opened. If on the contrary k_2 is much weaker than k_1, then upon pulling, contact *a* will first be opened and only afterwards contact *c*. If k_1 is sufficiently stiff, contact *b* will even first be closed before *c* is opened.

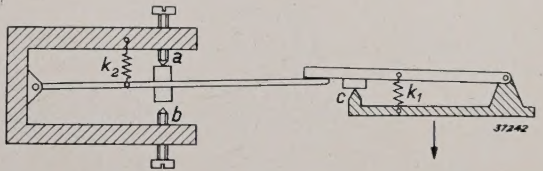

Fig. 1. Principle of the arrangement for testing contact pressures; *c* the switch to be tested, *a* and *b* auxiliary contacts.

The auxiliary contacts *a* and *b* are so adjusted that *a* is opened when the contact pressure of *c* is just decreased by 60 g by the pulling down, and so that *b* is closed when this decrease amounts to 120 g. Thus if the contact pressure of the switch in question lies within the desired limits, upon pulling down, *a* will first open, then *c* and finally *b* will be closed (order: *a* open, *c* open, *b* closed). Three relays *A*, *B* and *C* are operated by the three contacts *a*, *b* and *c*, and are connected in the manner shown in fig. 2. On the basis of this figure one ascertains that with each of the three switching orders mentioned the final result is that one of the three lamps —, 0 or + burns, by which means the qualification of the contact pressure being tested is obtained as "too weak", "good" or "too strong". By bending the contact springs a deviation can then immediately be improved.

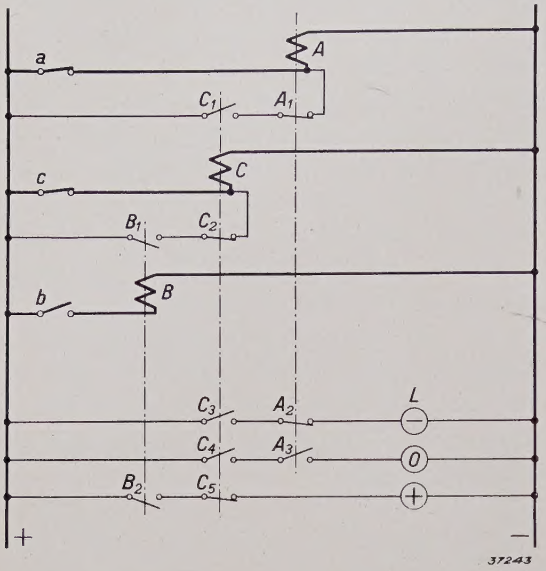

Fig. 2. Connections of the apparatus. The contacts are all shown in the initial state; current hereby flows through the relays *A* and *C* but not through *B*. Upon flow of current through a relay the corresponding switch rod (dash-dot line) is raised. Thus for example if *a* is opened relay *A* opens, with the result that the switches A_1 and A_2 are opened, A_0 closed. Upon opening *c* relay *C* opens, the switches C_1, C_3 and C_4 are thus closed, and C_2 and C_5 opened. Upon closing *b* relay *B* closes and the switches B_1 and B_2 are closed. If the switching order is: *c* open, *a* open, *b* closed, *C* then opens, *A* however remains closed (because C_1 is now closed and *a* therefore shunted), *B* closes; of the three lamps *L* only the one marked- burns. With the switching order: *a* open, *c* open, *b* closed, *A* and *C* open, *B* closes; only lamp O burns. With the order: *a* open, *b* closed, *c* open, *A* opens, *B* closes, *C* remains closed (because B_1 is now closed and *c* is shunted), and lamp + burns.

Fig. 3 is a photograph of the apparatus as constructed. The switch to be tested is slid into the holder *M*, and the upper contact strip is then placed above the pressure finger projecting from the apparatus. Upon pressing the holder down in the manner described one of the three lamps *L* is lighted.

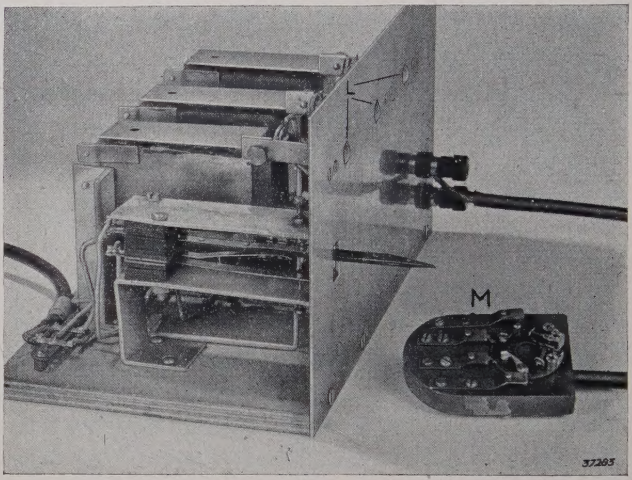

Fig. 3. Photograph of the apparatus. *M* holder, *L* lamps.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

1509: J. D. Fast: The preparation of metals by powder metallurgy and decomposition metallurgy (Öst. Chem. Z. **43**, 27-33 and 48-54, Febr. and Mar. 1940). (Original in German).

Following a consideration of the relationship between powder metallurgy and ceramic processes and of several forerunners of powder metallurgy, the different successive treatments used in the preparation of hard cemented carbides are dealt with and the influence of gases on the sintering process is discussed. Hypotheses are hereby developed about the coming into effect of the forces of cohesion upon compression and about the part which the oxide films always present on the grains of the metal powders play in this process. Furthermore the mechanism of the shrinkage phenomena occurring upon sintering is studied and the phenomena of recrystallization and coalescence occurring at the same time. As an example of the application of powder metallurgy the preparation of ductile tungsten is described, as well as the preparation of the so-called "hard cemented carbides" and several other applications.

Decomposition metallurgy is of particular importance in the preparation in a ductile form of the metals with a high melting point in the titanium group. A description is given of the method used. In conclusion the preparation of pure nickel and iron by the method of decomposition metallurgy is discussed.

The contents of this article have been partially discussed in Philips techn. Rev. **4**, 309, 1939 (The preparation of metals in a compact form by pressing and sintering) and **3**, 345, 1938 (Zirconium and its compounds with a high melting point).

1510: K. F. Niessen: Calculation of the electrical field strength produced at a given point by a half-wave aerial over a flat earth as a function of the total energy supplied to the aerial I (Physica **7**, 586-602, July 1940). (Original in German).

On the basis of an example it is explained how the vertical electric field at a point above a flat earth can be calculated when the field is induced by an aerial of a half wave length, whose lower extremity lies above the earth's surface. It is found possible to express this field with the help of the total energy supplied to the aerial, part of which is radiated (the effective part) and the rest absorbed by the earth (non-effective part). The problem is first solved for the radiation of a pure dipole which in the further treatment is laid at the middle of the aerial. The reflection formula, which is often used as an approximation in such problems, might here lead to quite incorrect results.

1511: J. L. Snoek: On the effective length of a small Barkhausen discontinuity (Physica **7**, 609-624, July 1940).

The irreversible part of the magnetization is given by the product of magnitude and number of the so-called Barkhausen discontinuities. At very low field strengths most ferromagnetic substances follow Rayleigh's law in close approximation, according to which law the irreversible part of the magnetization with a small hysteresis loop increases with the square of the maximum field strength. This law furnishes a condition which must be satisfied by the laws which govern the magnitude and number of the Barkhausen discontinuities. Very little is yet known about these laws; it is, however, established that with decreasing field strength the Barkhausen discontinuities become very small. The path of the lines of force of such a very small discontinuity can be calculated in advance, beginning with several plausible assumptions. In this way an "effective length" of the discontinuity is found, and on the basis of this it is possible to choose the most favourable experimental values for the detection of these very small discontinuities. The calculation shows that the effective length is equal to the product of the reversible permeability and the thickness of the wire.

1512: M. J. O. Strutt and K. S. Knol: Determinations of the magnetic permeability from resistance measurements on iron wires of varying structure at frequencies of the order of magnitude of 10^8 c/s., in connection with the magnitude of the elementary zones of Weiss (Physica **7**, 635-654, July 1940). (Original in German).

The permeability of iron wires at very high frequencies can with certain assumptions be determined from the ratio between A.C. and D.C. resistance. With the apparatus developed by the authors the A.C. resistance of several carefully prepared wires is measured up to frequencies of 3×10^8 c/s. At room temperature the permeability remains nearly constant up to these frequencies. Upon a lowering of the temperature to $-183°$C, which for these measurements is equivalent to an increase of the frequency to about 10^9 c/s., a decrease in the permeability takes place. The curves obtained give an indication that the permeability at higher frequencies possibly again assumes a constant value. The hypothesis that this behaviour may be ascribed to a very thin non-magnetic film on the surface of the iron wires is not confirmed by experiments with electrolytically deposited films of more than 10^{-4} cm thickness. A satisfactory interpretation is, however, possible in a manner indicated by R. Becker. This interpretation can be further worked out with a simple model proposed by G. Heller; in particular, with this model the order of magnitude of the elementary zones of Weiss can be determined for the different wires. The results obtained are compared with those of other investigators. In conclusion several unexplained problems are discussed and indications given for possible further experiments.

1513: C. J. Bakker: Het periodiek systeem der elementen (The periodic system of the elements, explanation of the plate). (Ned. T. Natuurk. **7**, 305-310, Aug. 1940).

The plate to be explained represents the periodic system of the elements. In each of the compartments of the chart is indicated: atomic number, atomic symbol, atomic weight according to the international table, electron configuration of the neutral atom in the usual notation, as well as the isotope relations graphically. Chemically analogous elements are indicated by striking colours. Although both by its arrangement of data and by its make-up the plate is already very instructive, in the explanation a further critical discussion of the electron configuration, isotope and radioactive properties may be found. The latter are also indicated in the chart as well.

1514*: J. van Niekerk and Miss M. S. C. Bliek: De methodiek der vitamine-D ijking op kuikens (The methods of vitamin D standardization on chicks) (Landbouwk. T. **52**, 349-353, May, June 1940).

This is a communication about a demonstration in Wageningen during the 10th Netherlands Agriculture Week. In the standardization on rats the difference between animalic and vegetable vitamin D is not manifested. This can, however, be established in breeding chicks whereby at the same time the information is obtained whether a product containing vitamin D is suitable for poultry feed and perhaps for cattle feeding also. With a simply composed feed, during the first 3 to 4 weeks of life, rickets occur which can easily be observed in an X-ray photograph on the heel joints of the chicks. Addition of vitamin D in different concentrations to the feed shows a relation between the extent of the rickets and the lack of vitamin D. A preparation consisting entirely of animalic vitamin D gives the antirachitic effect to the same degree as cod liver oil. The relation mentioned between the antirachitic effect and the concentration of animalic vitamin D given is determined in a standardization curve. The exposure technique in the X-ray examination is simple, large groups of chicks can be examined in a few hours.

1515: E. J. W. Verwey and J. H. de Boer: The potential curve of the alkali halide molecules (Rec. Trav. chim. Pays Bas **59**, 633-649, July-Aug. 1940).

To what degree the electrostatic picture of the ionic bond in vapours of the alkali halides is correct in the neighbourhood of the minimum of the potential curve is investigated for three points, namely: 1) the nuclear distances at absolute zero calculated from atomic distances determined with the help of electron diffraction at 1200 °C in the vapour and the atomic distances in the corresponding crystal lattices, 2) the fundamental frequencies of the atomic vibrations, calculated from the potential curves compared with the values from the spectra, and 3) the binding or molecular energies at absolute zero compared with thermal data. The expression for the energy $U = -e^2/r + b/r^n$ with $n = 11$ gives a correct picture. By taking into account the polarizations the picture is improved, and the molecular energies can also be calculated accurately within the errors of observation. For all alkali halides $n = 12$ is then found to be the best value. The exponential repulsion according to Born and Mayer is found incapable of being used.

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*) An adequite number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on applications to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.